

FUNCTIONALIZED MONOMERS FOR SYNTHESIS OF RUBBERY POLYMERS

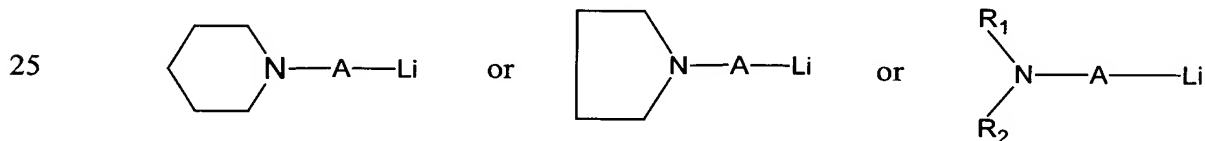
This is a continuation-in-part application of United States Patent Application Serial No. 10/624,188, filed on  
5 July 22, 2003, which is a continuation-in-part application of United States Patent Application Serial No. 10/384,020, filed on March 7, 2003, which claims the benefit of United States Provisional Patent Application Serial No. 60/404,081, filed on August 16, 2002, and United States  
10 Provisional Patent Application Serial No. 60/434,892, filed on December 19, 2002.

Background of the Invention

It is important for rubbery polymers that are used in  
15 tires, hoses, power transmission belts and other industrial products to have good compatibility with fillers, such as carbon black and silica. To attain improved interaction with fillers such rubbery polymers can be functionalized with various compounds, such as amines. United States  
20 Patent 4,935,471 discloses a process for preparing a polydiene having a high level of affinity for carbon black which comprises reacting a metal terminated polydiene with a capping agent selected from the group consisting of (a) halogenated nitriles having the structural formula  $X-A-C\equiv N$ ,  
25 wherein X represents a halogen atom and wherein A represents an alkylene group containing from 1 to 20 carbon atoms, (b) heterocyclic aromatic nitrogen containing compounds, and (c) alkyl benzoates. The capping agents disclosed by United States Patent 4,935,471 react with  
30 metal terminated polydienes and replace the metal with a terminal cyanide group, a heterocyclic aromatic nitrogen containing group or a terminal group which is derived from an alkyl benzoate. For example, if the metal terminated

polydiene is capped with a nitrile, it will result in the polydiene chains being terminated with cyanide groups. The use of heterocyclic aromatic nitrogen containing compounds as capping agents can result in the polydiene chains being  
5 terminated with a pyrrolyl group, an imidazolyl group, a pyrazolyl group, a pyridyl group, a pyrazinyl group, a pyrimidinyl group, a pyridazinyl group, an indolizinyll group, an isoindolyl group, a 3-H-indolyl group, a cinnolinyll group, a pyridinyl group, a .beta.-carbolinyll  
10 group, a perimidinyll group, a phenanthrolinyll group or the like.

United States Patent 4,935,471 also discloses that lithium amides are highly preferred initiators because they can be used to prepare polydienes which are terminated with  
15 polar groups at both ends of their polymer chains. The extra polar functionality provided by lithium amides results in increased interaction with carbon black resulting in better polymer-carbon black dispersion. The lithium amides disclosed by United States Patent 4,935,471  
20 include lithium pyrrolidide. United States Patent 4,935,471 also indicates that preferred initiators include amino alkyl lithium compounds of the structural formula:

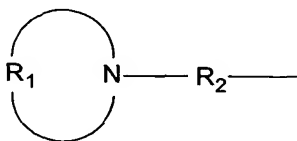


wherein A represents an alkylene group containing from 1 to  
20 carbon atoms, and wherein R<sub>1</sub> and R<sub>2</sub> can be the same or  
30 different and represent alkyl groups containing from 1 to 20 carbon atoms.

It is also desirable for synthetic rubbers to exhibit low levels of hysteresis. This is particularly important

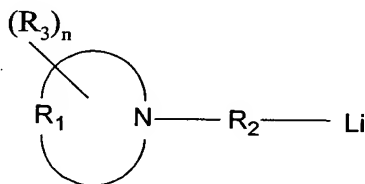
in the case of rubbers that are used in tire tread compounds. Such polymers are normally compounded with sulfur, carbon black, accelerators, antidegradants and other desired rubber chemicals and are then subsequently  
5 vulcanized or cured into the form of a useful article. It has been established that the physical properties of such cured rubbers depend upon the degree to which the carbon black is homogeneously dispersed throughout the polydiene rubber. This is in turn related to the level of affinity  
10 that carbon black has for the rubber. This can be of practical importance in improving the physical characteristics of rubber articles that are made utilizing polydiene rubbers. For example, the rolling resistance and tread wear characteristics of tires can be improved by  
15 increasing the affinity of carbon black to the rubbery polymers utilized therein. Therefore, it would be highly desirable to improve the affinity of a given polydiene rubber for carbon black and/or silica. This is because a better dispersion of carbon black throughout polydiene  
20 rubbers which are utilized in compounding tire tread compositions results in a lower hysteresis value and consequently tires made therefrom have lower rolling resistance. It is also known that a major source of hysteresis is due to polymer chain ends that are not  
25 capable of full elastic recovery. Accordingly, improving the affinity of the rubber chain ends to the filler is extremely important in reducing hysteresis.

United States Patent 6,080,835 discloses a functionalized elastomer comprising: a functional group  
30 defined by the formula:



where  $R_1$  is a selected from the group consisting of a divalent alkylene group, an oxy-alkylene group, an amino alkylene group, and a substituted alkylene group, each  
 5 group having from about 6 to about 20 carbon atoms,  $R_2$  is covalently bonded to the elastomer and is selected from the group consisting of a linear-alkylene group, a branched-alkylene group, and a cyclo-alkylene group, each group having from about 2 to about 20 carbon atoms.

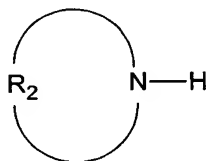
10 United States Patent 5,932,662 discloses a method of preparing a polymer comprising: preparing a solution of one or more anionically polymerizable monomers in a solvent; and, polymerizing under effective conditions, said monomers in the presence of a polymerization initiator having the  
 15 formula



20 wherein  $R_1$  is a divalent alkylene, an oxy- or amino-alkylene having from 6 to about 20 carbon atoms; and,  $R_2$  is a linear-alkylene, branched-alkylene, or cyclo-alkylene having from about 2 to about 20 carbon atoms, Li is a lithium atom  
 25 bonded directly to a carbon atom of  $R_2$ ; and  $R_3$  is a tertiary amino, an alkyl having from 1 to about 12 carbon atoms; an aryl having from about 6 to about 20 carbon atoms; an alkaryl having from about 7 to about 20 carbon atoms; an alkenyl having from about 2 to about 12 carbon atoms; a  
 30 cycloalkyl having from about 5 to about 20 carbon atoms; a cycloalkenyl having from about 5 to about 20 carbon atoms; a bicycloalkyl having from about 6 to about 20 carbon atoms; and, a bicycloalkenyl having from about 6 to about

20 carbon atoms; where n is an integer of from 0 to about 10.

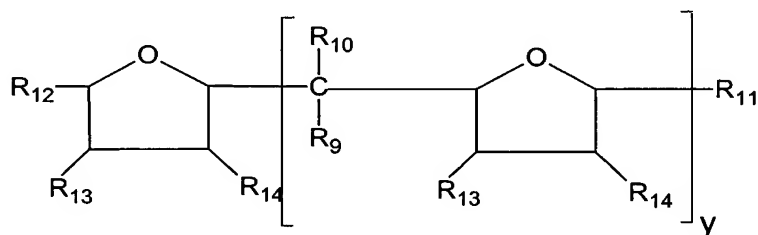
United States Patent 6,084,025 discloses a functionalized polymer prepared by a process comprising the steps of: preparing a solution of a cyclic amine compound, an organolithium compound, and from 3 to about 300 equivalents, based upon one equivalent of lithium, of a monomer selected from vinyl aromatic monomers, and mixtures thereof, where said cyclic amine compound is defined by the formula



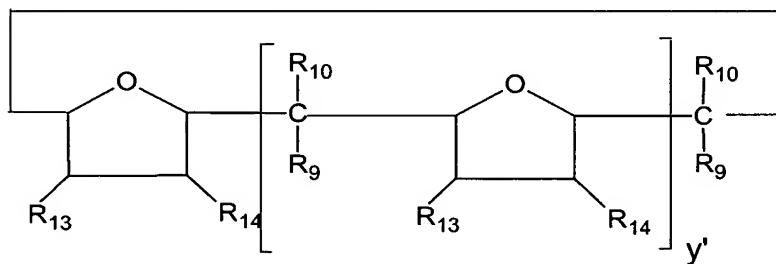
where R<sub>2</sub> is selected from the group consisting of an alkylene, substituted alkylene, bicycloalkane, and oxy- or N-alkylamino-alkylene group having from about 3 to about 16 methylene groups, N is a nitrogen atom, and H is a hydrogen atom, thereby forming a polymerization initiator having the formula A(SOL)<sub>y</sub>Li, where Li is a lithium atom, SOL is a divalent hydrocarbon group having from 3 to about 300 polymerized monomeric units, y is from 0.5 to about 3, and A is a cyclic amine radical derived from said cyclic amine; charging the solution containing A(SOL)<sub>y</sub>Li with from about 0.01 to about 2 equivalents per equivalent of lithium of a chelating reagent, and an organic alkali metal compound selected from compounds having the formula R<sub>4</sub>OM, R<sub>5</sub>C(O)OM, R<sub>6</sub>R<sub>7</sub>NM, and R<sub>8</sub>SO<sub>3</sub>M, where R<sub>4</sub>, R<sub>5</sub>, R<sub>6</sub>, R<sub>7</sub>, and R<sub>8</sub> are each selected from alkyls, cycloalkyls, alkenyls, aryls, or phenyls, having from 1 to about 12 carbon atoms; and where M is Na, K, Rb or Cs, and sufficient monomer to form a living polymeric structure; and quenching the living

polymeric structure.

In the initiator systems of United States Patent 6,084,025 a chelating reagent can be employed to help prevent heterogeneous polymerization. The reagents that are reported as being useful include tetramethylethylenediamine (TMEDA), oxolanyl cyclic acetals, and cyclic oligomeric oxolanyl alkanes. The oligomeric oxolanyl alkanes may be represented by the structural formula:



and



wherein  $\text{R}_9$  and  $\text{R}_{10}$  independently are hydrogen or an alkyl group and the total number of carbon atoms in  $-\text{CR}_9\text{R}_{10}-$  ranges between one and nine inclusive;  $y$  is an integer of 1 to 5 inclusive;  $y'$  is an integer of 3 to 5 inclusive; and  $\text{R}_{11}$ ,  $\text{R}_{12}$ ,  $\text{R}_{13}$ , and  $\text{R}_{14}$  independently are  $-\text{H}$  or  $-\text{C}_n\text{H}_{2n+1}$ , wherein  $n=1$  to 6.

United States Patent 6,344,538 discloses functionalized monomers and polymerized functionalized monomers selected from the group consisting of 2-(N,N-

dimethylaminomethyl)-1,3-butadiene, 2-(N,N-diethylaminomethyl)-1,3-butadiene, 2-(N,N-di-n-propylaminomethyl)-1,3-butadiene, 2-(cyanomethyl)-1,3-butadiene, 2-(aminomethyl)-1,3-butadiene, 2-(hydroxymethyl)-1,3-butadiene, 2-(carboxymethyl)-1,3-butadiene, 2-(acetoxymethyl)-1,3-butadiene, 2-(2-alkoxy-2-oxoethyl)-1,3-butadiene, 2,3-bis(cyanomethyl)-1,3-butadiene, 2,3-bis(dialkylaminomethyl)-1,3-butadiene, 2,3-bis(4-ethoxy-4-oxobutyl)-1,3-butadiene and 2,3-bis(3-cyanopropyl)-1,3-butadiene, and methods for preparing such functionalized diene monomers and polymers.

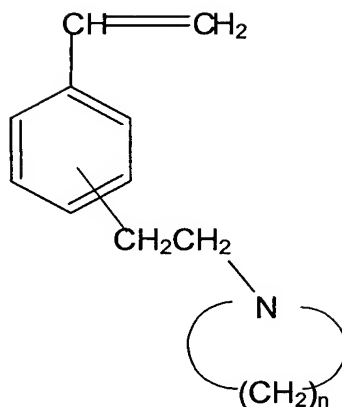
#### Summary of the Invention

The present invention relates to functionalized monomers that can be polymerized into rubbery polymers having low hysteresis and good compatibility with fillers, such as carbon black and silica. The functionalized monomers of this invention are typically incorporated into the rubbery polymer by being copolymerized with one or more conjugated diolefin monomers and optionally other monomers that are copolymerizable therewith, such as vinyl aromatic monomers. In any case, improved polymer properties are realized because the functionalized monomers of this invention improve the compatibility of the rubber with the types of fillers that are typically used in rubber compounds, such as carbon black and silica.

This invention more specifically discloses monomers that are particularly useful for copolymerization with conjugated diolefin monomers to produce rubbery polymers having better compatibility with fillers. The monomers of this invention have a structural formula selected from the group consisting of

(a)

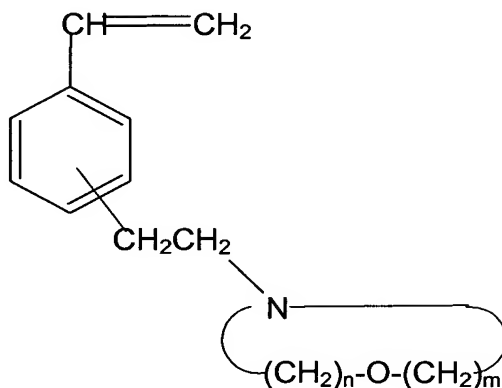
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10 wherein n represents an integer from 4 to about 10,

(b)

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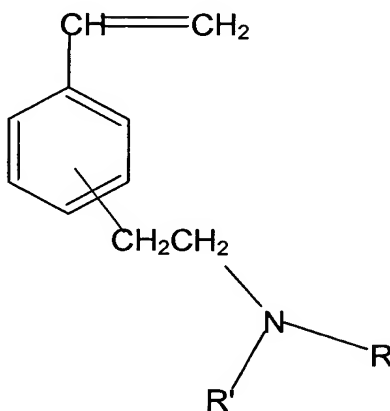
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wherein n represents an integer from 0 to about 10 and  
wherein m represents an integer from 0 to about 10, with  
the proviso that the sum of n and m is at least 4;

25

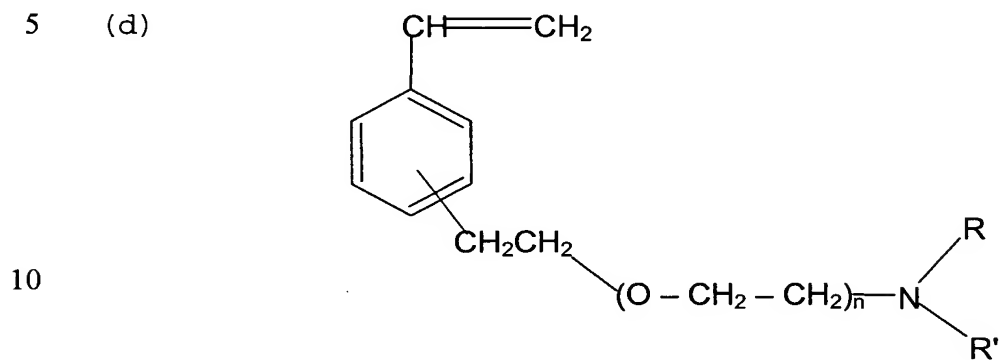
(c)

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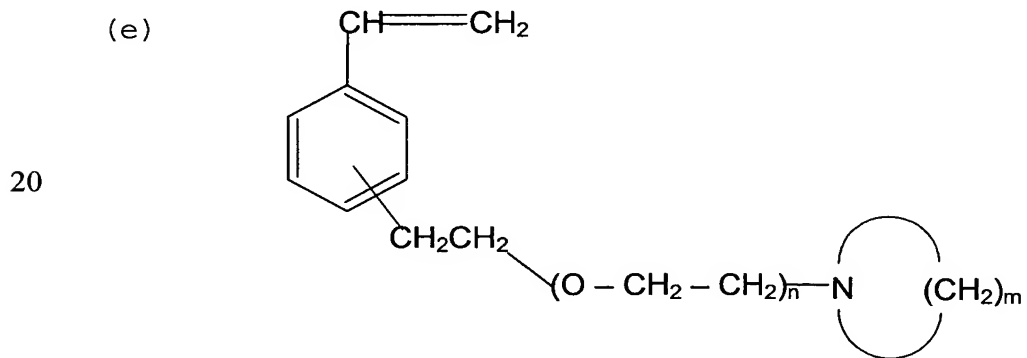




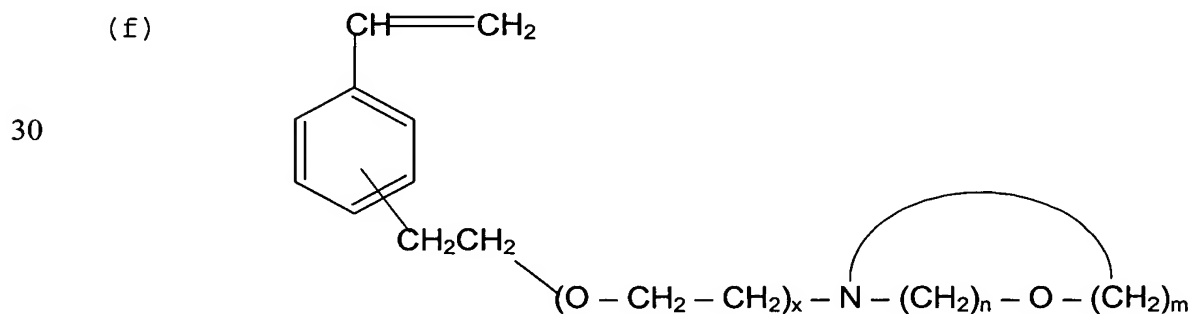
wherein R and R' can be the same or different and represent alkyl, allyl groups or alkoxy groups containing from 1 to about 10 carbon atoms; (d)



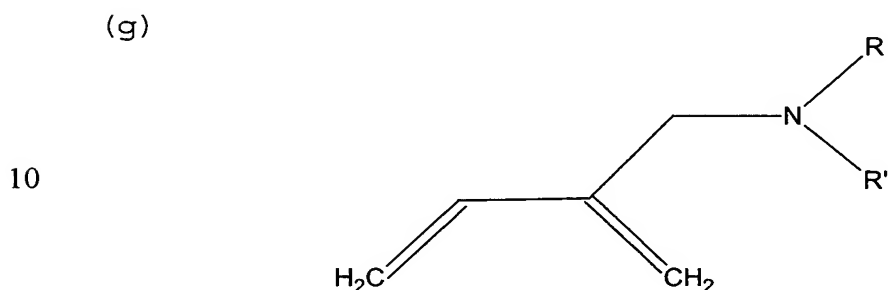
wherein n represents an integer from 1 to about 10, and wherein R and R' can be the same or different and represent alkyl groups containing from 1 to about 10 carbon atoms;



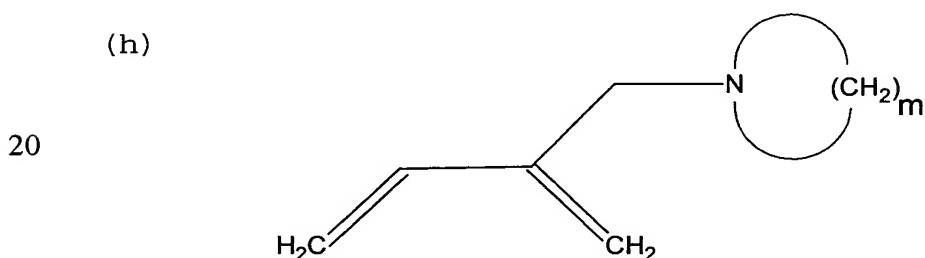
wherein n represents an integer from 1 to about 10 and wherein m represents an integer from 4 to about 10;



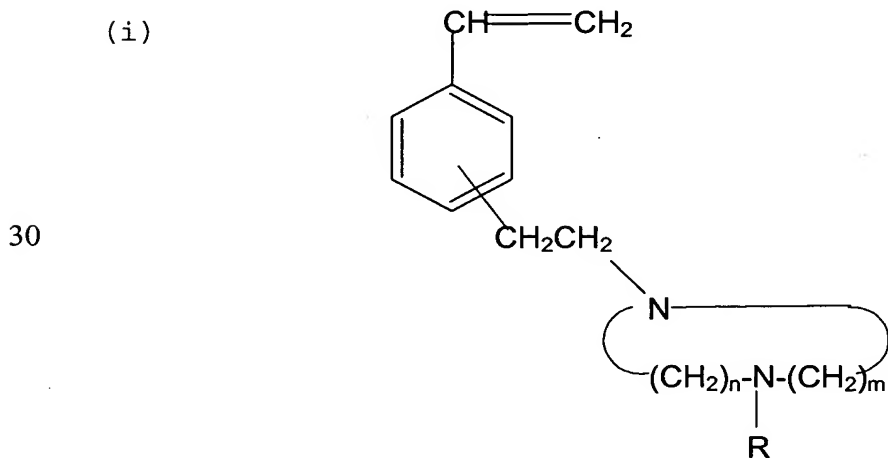
wherein x represents an integer from 1 to about 10, wherein  
n represents an integer from 0 to about 10 and wherein m  
represents an integer from 0 to about 10, with the proviso  
5 that the sum of n and m is at least 4;



wherein R and R' can be the same or different and represent  
15 allyl, alkoxyl or alkyl groups containing from 1 to about  
10 carbon atoms,



wherein m represents an integer from about 4 to about 10;  
25

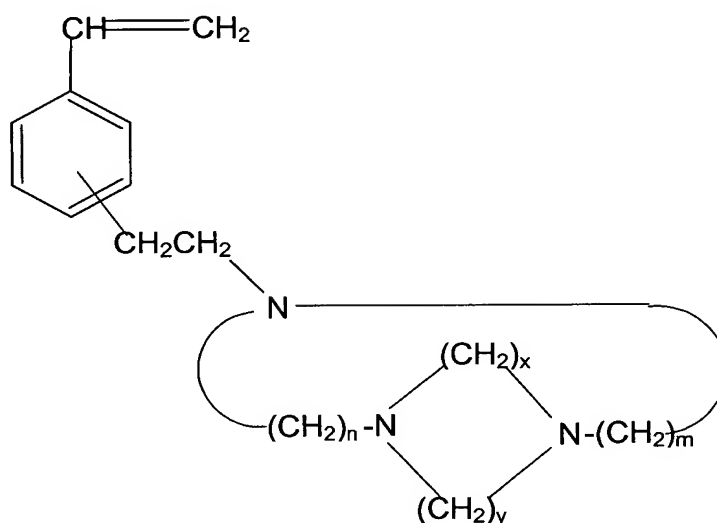


wherein R represents a hydrogen atom or an alkyl group containing from 1 to about 10 carbon atoms, wherein n represents an integer from 0 to about 10, and wherein m represents an integer from 0 to about 10, with the proviso that the sum of n and m is at least 4;

(j)

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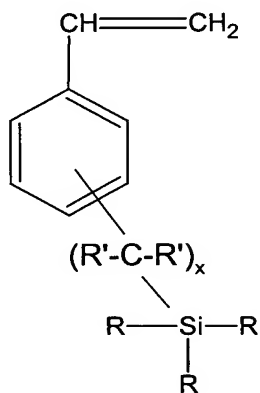


wherein n represents an integer from 0 to about 10, wherein m represents an integer from 0 to about 10, wherein x represents an integer from 1 to about 10, and wherein y represents an integer from 1 to about 10; and

(k)

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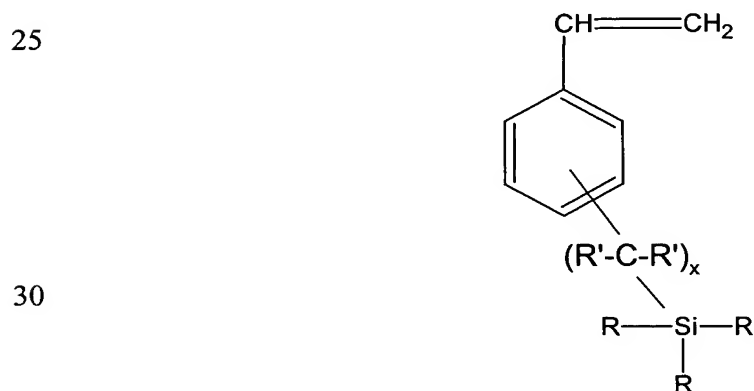


wherein the  $\text{R}'$  groups in repeat units and in different

repeat units can be the same or different and represent hydrogen atoms or alkyl groups containing from 1 to about 4 carbon atoms, wherein x represents an integer from 1 to about 10, and wherein the R groups in repeat units and in  
5 different repeat units can be the same or different and represent alkyl groups containing from 1 to about 10 carbon atoms or alkoxy groups containing from 1 to about 10 carbon atoms.

One aspect of this invention is based upon the  
10 unexpected finding that random copolymers of 1,3-butadiene monomer and 3-(2-pyrrolidinoethyl) styrene and/or 4-(2-pyrrolidinoethyl) styrene having a low vinyl content can be synthesized by anionic polymerization at normal polymerization temperatures without the need for a  
15 conventional polar modifier.

The subject invention more specifically discloses a process for synthesizing a rubbery polymer that comprises copolymerizing at least one conjugated diolefin monomer and at least one functionalized monomer in an organic solvent  
20 at a temperature which is within the range of 20°C to about 100°C, wherein the polymerization is initiated with an anionic initiator, wherein the functionalized monomer is of the structural formula:

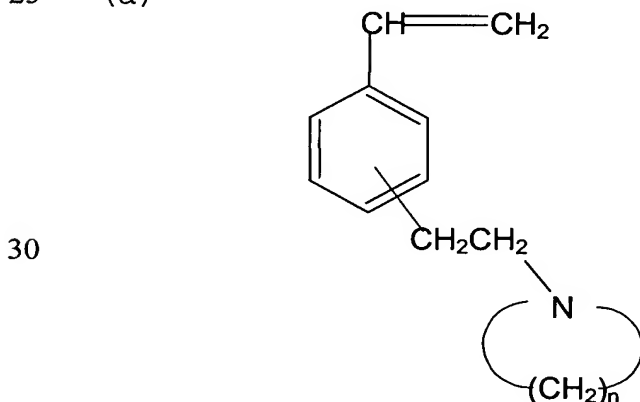


wherein the R' groups in repeat units and in different

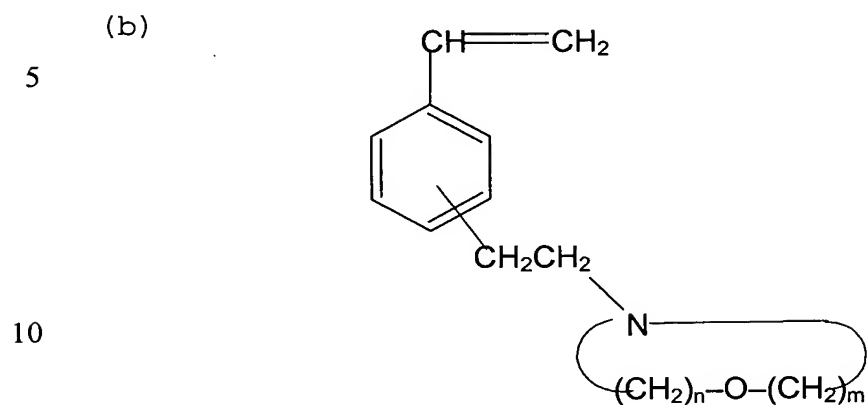
repeat units can be the same or different and represent hydrogen atoms or alkyl groups containing from 1 to about 4 carbon atoms, wherein x represents an integer from 1 to about 10, and wherein the R groups in repeat units and in  
5 different repeat units can be the same or different and represent alkyl groups containing from 1 to about 10 carbon atoms or alkoxy groups containing from 1 to about 10 carbon atoms. In such functionalized monomers it is preferred for x to represent an integer from 1 to about 4. It is also  
10 preferred for R' to represent hydrogen atoms or methyl groups. It is further preferred for R to represent alkoxy groups containing from 1 to 4 carbon atoms.

The subject invention further reveals a tire which is comprised of a generally toroidal-shaped carcass with an  
15 outer circumferential tread, two spaced beads, at least one ply extending from bead to bead and sidewalls extending radially from and connecting said tread to said beads, wherein said tread is adapted to be ground-contacting, and wherein said tread is comprised of (I) a filler, and (II)  
20 rubbery polymer which is comprised of repeat units that are derived from (1) at least one conjugated diolefin monomer, and (2) at least one monomer having a structural formula selected from the group consisting of

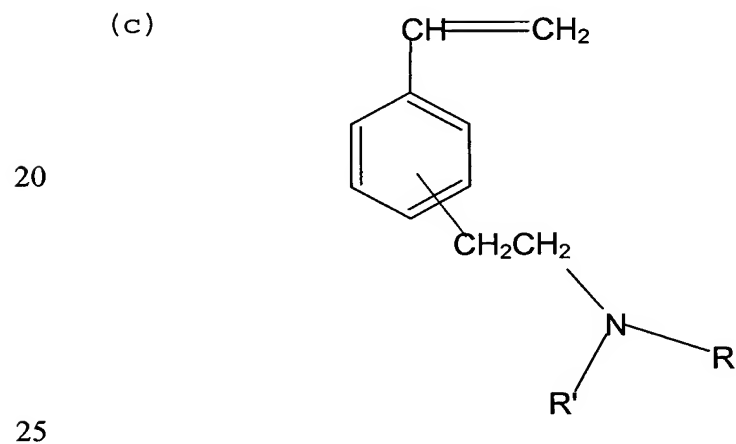
25 (a)



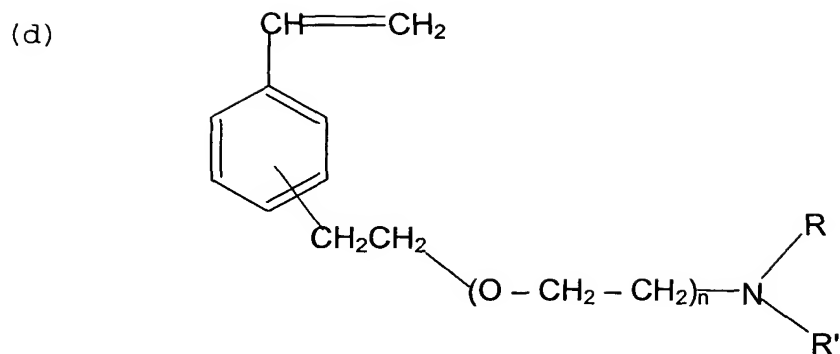
wherein n represents an integer from 4 to about 10,



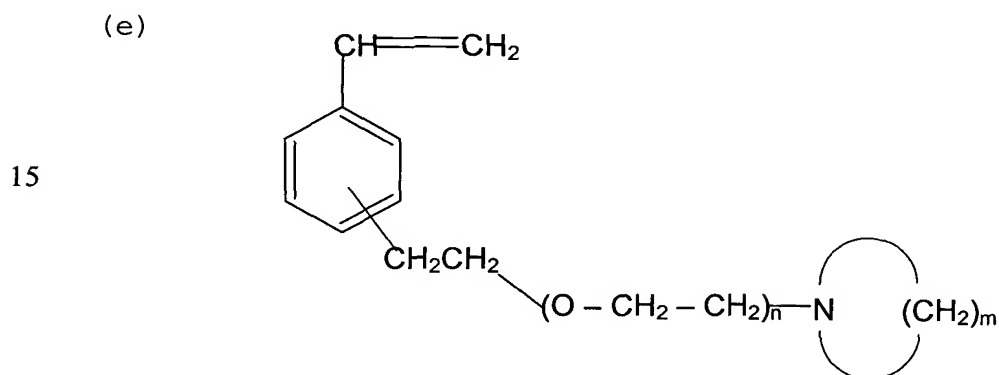
wherein n represents an integer from 0 to about 10 and  
 wherein m represents an integer from 0 to about 10, with  
 15 the proviso that the sum of n and m is at least 4;



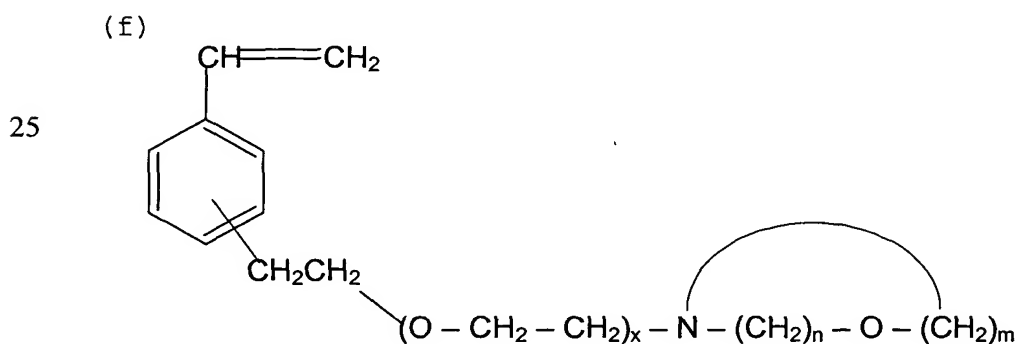
wherein R and R' can be the same or different and represent  
 allyl groups or alkoxy groups containing from 1 to about 10  
 carbon atoms;



wherein n represents an integer from 1 to about 10, and  
 wherein R and R' can be the same or different and represent  
 alkyl groups containing from 1 to about 10 carbon atoms;



wherein n represents an integer from 1 to about 10 and  
 wherein m represents an integer from 4 to about 10;

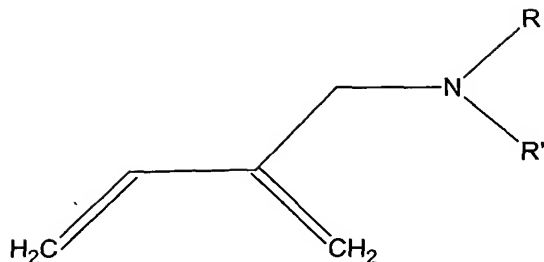


wherein x represents an integer from 1 to about 10, wherein  
 n represents an integer from 0 to about 10 and wherein m  
 represents an integer from 0 to about 10, with the proviso

that the sum of n and m is at least 4;

(g)

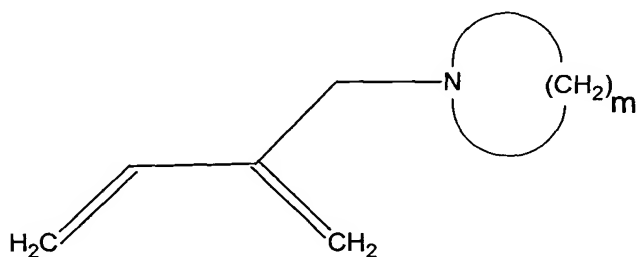
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wherein R and R' can be the same or different and represent  
10 alkyl groups containing from 1 to about 10 carbon atoms,

(h)

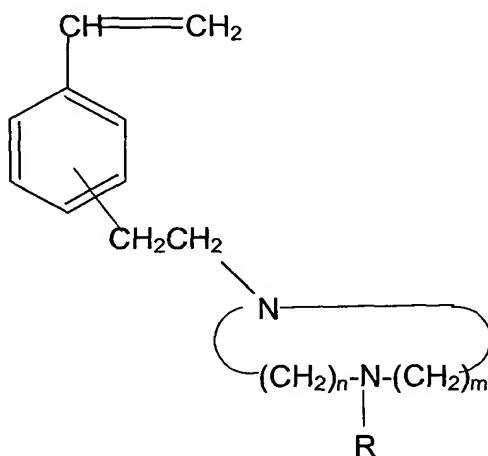
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wherein m represents an integer from about 4 to about 10;

20 (i)

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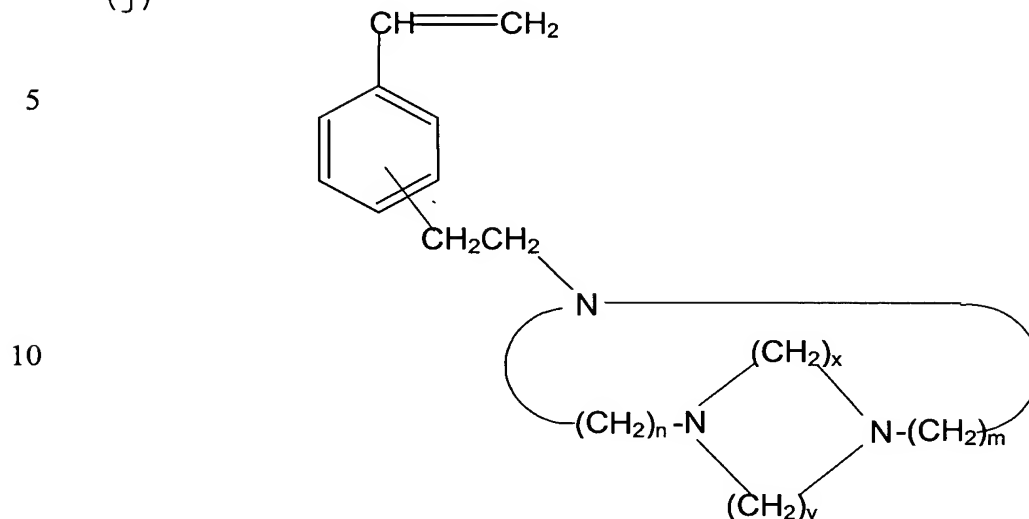


30 wherein R represents a hydrogen atom or an alkyl group  
containing from 1 to about 10 carbon atoms, wherein n  
represents an integer from 0 to about 10, and wherein m  
represents an integer from 0 to about 10, with the proviso



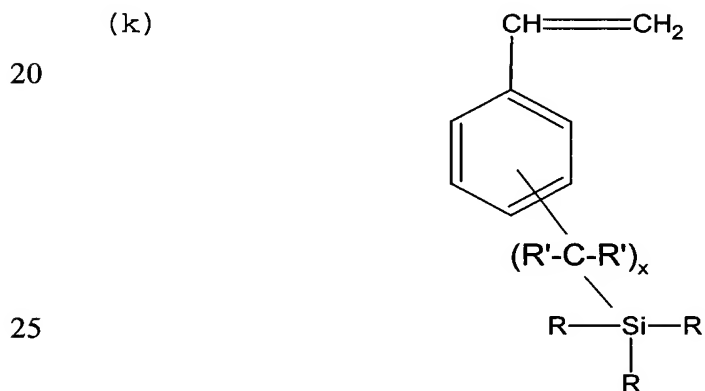
that the sum of n and m is at least 4;

(j)



wherein n represents an integer from 0 to about 10, wherein  
 15 m represents an integer from 0 to about 10, wherein x  
 represents an integer from 1 to about 10, and wherein y  
 represents an integer from 1 to about 10; and

(k)



wherein the R' groups in repeat units and in different  
 repeat units can be the same or different and represent  
 hydrogen atoms or alkyl groups containing from 1 to about 4  
 30 carbon atoms, wherein x represents an integer from 1 to  
 about 10, and wherein the R groups in repeat units and in  
 different repeat units can be the same or different and  
 represent alkyl groups containing from 1 to about 10 carbon

atoms or alkoxy groups containing from 1 to about 10 carbon atoms.

The present invention further discloses a process for synthesizing an amino ethyl styrene monomer which  
5 comprises: (1) reacting divinyl benzene with a cyclic amine in a reacting mixture in the presence of an alkyl lithium compound at a temperature which is within the range of -80°C to 80°C to produce the amino ethyl styrene; and (2) deactivating the alkyl lithium compound by adding an  
10 alcohol or water to the reaction mixture containing the amino ethyl styrene. This process is preferable conducted at a temperature which is within the range of about -20°C to about 50°C and is most preferable conducted at a temperature is within the range of about -10°C to about  
15 25°C. The alkyl lithium compound is typically present at a level which is within the range of about 0.5 mole percent to about 5 mole percent, based upon the molar amount of cyclic amine present. The alkyl lithium compound is preferably present at a level which is within the range of  
20 about 1 mole percent to about 4 mole percent and is more preferably present at a level which is within the range of about 1.5 mole percent to about 2.5 mole percent, based upon the molar amount of cyclic amine present.

#### 25 Detailed Description of the Invention

The functionalized monomers of this invention can be copolymerized into virtually any type of synthetic rubber. In most cases the functionalized monomer will be copolymerized with at least one conjugated diolefin  
30 monomer. Optionally, other monomers that are copolymerizable with conjugated diolefin monomers, such as vinyl aromatic monomers, can also be included in the polymerization. In any case, typically from about 0.1 phm

(parts by weight by 100 parts by weight of monomers) to about 100 phm of the functionalized monomer will be included in the polymerization. More typically, from about 0.05 phm to about 20 phm of the functionalized monomer will be included in the rubbery polymer. Good results can normally be attained by including 0.1 phm to 10 phm of the functionalized monomer in the rubbery polymer. In most cases 0.1 phm to 1 phm of the functionalized monomer is included in the polymerization receipt. It is typically most preferred to include 0.3 phm to 0.7 phm of the functionalized monomer in the polymerization receipt.

According to this invention, polymerization and recovery of polymer are suitably carried out according to various methods suitable for diene monomer polymerization processes. This includes batchwise, semi-continuous, or continuous operations under conditions that exclude air and other atmospheric impurities, particularly oxygen and moisture. The polymerization of the functionalized monomers of the invention may also be carried out in a number of different polymerization reactor systems, including but not limited to bulk polymerization, vapor phase polymerization, solution polymerization, suspension polymerization, emulsion polymerization, and precipitation polymerization systems. The commercially preferred methods of polymerization are solution polymerization and emulsion polymerization.

The polymerization reaction may use a free radical initiator, a redox initiator, an anionic initiator, a cationic initiator, or a Zeigler-Natta catalyst system. The preferred initiation system depends upon the particular monomers being polymerized and the desired characteristics of the rubbery polymer being synthesized. In emulsion polymerizations free radical initiators are typically

utilized. In solution polymerizations Zeigler-Natta catalyst systems or anionic initiators, such as alkyl lithium compounds, are typically employed to initiate the polymerization. An advantage of free radical  
5 polymerization is that reactions can typically be carried out under less rigorous conditions than ionic polymerizations. Free radical initiation systems also exhibit a greater tolerance of trace impurities.

Examples of free radical initiators that are useful in  
10 the practice of the present invention are those known as "redox" initiators, such as combinations of chelated iron salts, sodium formaldehyde sulfoxylate, and organic hydroperoxides. Representative of organic hydroperoxides are cumene hydroperoxide, paramenthane hydroperoxide, and  
15 tertiary butyl hydroperoxide. Tertiary butyl hydroperoxide (t-BHP), tertiary butyl peracetate (t-BPA) and "azo" initiators, such as azobisisobutyronitrile (AIBN), are preferred.

The reaction temperature is typically maintained in  
20 the range of 0°C to 150°C. Temperatures between about 20 and 80°C are generally preferred. The reaction pressure is not critical. It is typically only sufficiently high to maintain liquid phase reaction conditions; it may be autogenic pressure, which will vary depending upon the  
25 components of the reaction mixture and the temperature, or it may be higher, e.g., up to 1000 psi.

In batch operations, the polymerization time of functionalized diene monomers can be varied as desired; it may vary, for example, from a few minutes to several days.  
30 Polymerization in batch processes may be terminated when monomer is no longer absorbed, or earlier, if desired, e.g., if the reaction mixture becomes too viscous. In continuous operations, the polymerization mixture may be

passed through a reactor of any suitable design. The polymerization reactions in such cases are suitably adjusted by varying the residence time. Residence times vary with the type of reactor system and range, for  
5 example, from 10 to 15 minutes to 24 or more hours.

The concentration of monomer in the reaction mixture may vary upward from 5 percent by weight of the reaction mixture, depending on the conditions employed; the range from 20 to 80 percent by weight is preferred.

10 The polymerization reactions according to this invention may be carried out in a suitable solvent that is liquid under the conditions of reaction and relatively inert. The solvent may have the same number of carbon atoms per molecule as the diene reactant or it may be in a  
15 different boiling range. Preferred as solvents are alkane and cycloalkane hydrocarbons. Suitable solvents are, for example, hexane, cyclohexane, methylcyclohexane, or various saturated hydrocarbon mixtures. Aromatic hydrocarbons such as benzene, toluene, isopropylbenzene, xylene, or  
20 halogenated aromatic compounds such as chlorobenzene, bromobenzene, or orthodichlorobenzene may also be employed. Other useful solvents include tetrahydrofuran and dioxane.

Conventional emulsion recipes may also be employed with the present invention; however, some restrictions and  
25 modifications may arise either from the polymerizable monomer itself, or the polymerization parameters. Ionic surfactants, known in the art, including sulfonate detergents and carboxylate, sulfate, and phosphate soaps are useful in this invention. The level of ionic  
30 surfactant is computed based upon the total weight of the organic components and may range from about 2 to 30 parts by weight of ionic surfactant per 100 parts by weight of organic components.

Preferably the polymerization is carried out to complete functionalized diene monomer conversion in order to incorporate essentially all of the polymerizable functional group-bearing monomer. Incremental addition, or  
5 a chain transfer agent, may be used in order to avoid excessive gel formation. Such minor modifications are within the skill of the artisan. After the polymerization is complete, the polymer is recovered from a slurry or solution of the polymer. A simple filtration may be  
10 adequate to separate polymer from diluent. Other means for separating polymer from diluent may be employed. The polymer may be treated, separately or while slurried in the reaction mixture, in order to separate residues. Such treatment may be with alcohols such as methanol, ethanol,  
15 or isopropanol, with acidified alcohols, or with other similar polar liquids. In many cases the polymers are obtained in hydrocarbon solutions and the polymer can be recovered by coagulation with acidified alcohol, e.g., rapidly stirred methanol or isopropanol containing 2%  
20 hydrochloric acid. Following this initial coagulation, the polymers may be washed several more times in methanol.

The functionalized diene monomers according to the present invention may also be polymerized with one or more comonomers. Some adjustments in the polymerization recipe  
25 or reaction conditions may be necessary to obtain a satisfactory rate of polymer formation, depending on the amount of functionalized monomer included and the other monomers involved. Examples of comonomers that are useful in the practice of this invention are diene monomers such  
30 as butadiene, isoprene, and hexadienes. One may, in addition to the diene monomers, use a vinyl monomer such as styrene,  $\alpha$ -methylstyrene, divinyl benzene, vinyl chloride, vinyl acetate, vinylidene chloride, methyl methacrylate,

ethyl acrylate, vinylpyridine, acrylonitrile, methacrylonitrile, methacrylic acid, itaconic acid and acrylic acid. Mixtures of different functionalized monomers and mixtures of different comonomers may be used. The  
5 monomer charge ratio by weight is normally from about 0.10/99.9 to 99.9/0.10 functionalized monomer to comonomer (including any additional vinyl monomer). A charge ratio by weight of about 5/95 to about 80/20 is preferred with 10/90 to 40/60 the most preferred. According to one  
10 embodiment, the weight ratio of functionalized diene monomer to diene monomer to vinyl monomer may range from 5:75:20 to 95:5:0. Ratios will vary depending on the amount of chemical functionality desired to be incorporated and on the reactivity ratios of the monomers in the  
15 particular polymerization system used.

The functionalized monomers of this invention offer a unique ability to randomly copolymerize with conjugated diolefin monomers in solution polymerizations that are conducted at temperatures of 20°C or higher. The  
20 functionalized monomers of this invention can be incorporated into virtually any type of rubbery polymer that is capable of being made by solution polymerization with an anionic initiator or Zeigler-Natta type of catalyst. The polymerization employed in synthesizing the  
25 rubbery polymers will normally be carried out in a hydrocarbon solvent. Such hydrocarbon solvents are comprised of one or more aromatic, paraffinic or cycloparaffinic compounds. These solvents will normally contain from about 4 to about 10 carbon atoms per molecule  
30 and will be liquid under the conditions of the polymerization. Some representative examples of suitable organic solvents include pentane, isooctane, cyclohexane, methylcyclohexane, isohexane, n-heptane, n-octane, n-

hexane, benzene, toluene, xylene, ethylbenzene, diethylbenzene, isobutylbenzene, petroleum ether, kerosene, petroleum spirits, petroleum naphtha, and the like, alone or in admixture.

5           In the solution polymerization, there will normally be from 5 to 30 weight percent monomers in the polymerization medium. Such polymerization media are, of course, comprised of the organic solvent and monomers. In most cases, it will be preferred for the polymerization medium  
10 to contain from 10 to 25 weight percent monomers. It is generally more preferred for the polymerization medium to contain 15 to 20 weight percent monomers.

          The synthetic rubbers made by the process of this invention can be made by random copolymerization of the  
15 functionalized monomer with a conjugated diolefin monomer or by the random terpolymerization of the functionalized monomer with a conjugated diolefin monomer and a vinyl aromatic monomer. It is, of course, also possible to make such rubbery polymers by polymerizing a mixture of  
20 conjugated diolefin monomers with one or more ethylenically unsaturated monomers, such as vinyl aromatic monomers. The conjugated diolefin monomers which can be utilized in the synthesis of rubbery polymers which can be coupled in accordance with this invention generally contain from 4 to  
25 12 carbon atoms. Those containing from 4 to 8 carbon atoms are generally preferred for commercial purposes. For similar reasons, 1,3-butadiene and isoprene are the most commonly utilized conjugated diolefin monomers. Some additional conjugated diolefin monomers that can be  
30 utilized include 2,3-dimethyl-1,3-butadiene, piperylene, 3-butyl-1,3-octadiene, 2-phenyl-1,3-butadiene, and the like, alone or in admixture.

          Some representative examples of ethylenically



unsaturated monomers that can potentially be polymerized into rubbery polymers that contain the functionalized monomers of this invention include alkyl acrylates, such as methyl acrylate, ethyl acrylate, butyl acrylate, methyl  
5 methacrylate and the like; vinylidene monomers having one or more terminal  $\text{CH}_2=\text{CH}-$  groups; vinyl aromatics such as styrene,  $\alpha$ -methylstyrene, bromostyrene, chlorostyrene, fluorostyrene and the like;  $\alpha$ -olefins such as ethylene, propylene, 1-butene and the like; vinyl halides, such as  
10 vinylbromide, chloroethane (vinylchloride), vinylfluoride, vinyliodide, 1,2-dibromoethene, 1,1-dichloroethene (vinylidene chloride), 1,2-dichloroethene and the like; vinyl esters, such as vinyl acetate;  $\alpha,\beta$ -olefinically unsaturated nitriles, such as acrylonitrile and  
15 methacrylonitrile;  $\alpha,\beta$ -olefinically unsaturated amides, such as acrylamide, N-methyl acrylamide, N,N-dimethylacrylamide, methacrylamide and the like.

Rubbery polymers which are copolymers of one or more diene monomers with one or more other ethylenically  
20 unsaturated monomers will normally contain from about 50 weight percent to about 99 weight percent conjugated diolefin monomers and from about 1 weight percent to about 50 weight percent of the other ethylenically unsaturated monomers in addition to the conjugated diolefin monomers.  
25 For example, copolymers of conjugated diolefin monomers with vinylaromatic monomers, such as styrene-butadiene rubbers which contain from 50 to 95 weight percent conjugated diolefin monomers and from 5 to 50 weight percent vinylaromatic monomers, are useful in many  
30 applications.

Vinyl aromatic monomers are probably the most important group of ethylenically unsaturated monomers which are commonly incorporated into polydiene rubbers. Such

vinyl aromatic monomers are, of course, selected so as to be copolymerizable with the conjugated diolefin monomers being utilized. Generally, any vinyl aromatic monomer which is known to polymerize with organolithium initiators  
5 can be used. Such vinyl aromatic monomers typically contain from 8 to 20 carbon atoms. Usually, the vinyl aromatic monomer will contain from 8 to 14 carbon atoms. The most widely used vinyl aromatic monomer is styrene. Some examples of vinyl aromatic monomers that can be  
10 utilized include styrene, 1-vinylnaphthalene, 2-vinylnaphthalene,  $\alpha$ -methylstyrene, 4-phenylstyrene, 3-methylstyrene and the like.

Some representative examples of rubbery polymers that can be functionalized with the functionalized monomers of  
15 this invention include polybutadiene, polyisoprene, styrene-butadiene rubber (SBR),  $\alpha$ -methylstyrene-butadiene rubber,  $\alpha$ -methylstyrene-isoprene rubber, styrene-isoprene-butadiene rubber (SIBR), styrene-isoprene rubber (SIR), isoprene-butadiene rubber (IBR),  $\alpha$ -methylstyrene-isoprene-  
20 butadiene rubber and  $\alpha$ -methylstyrene-styrene-isoprene-butadiene rubber. In cases where the rubbery polymer is comprised of repeat units that are derived from two or more monomers, the repeat units which are derived from the different monomers, including the functionalized monomers,  
25 will normally be distributed in an essentially random manner. The repeat units that are derived from the monomers differ from the monomer in that a double bond is normally consumed in by the polymerization reaction.

The rubbery polymer can be made by solution  
30 polymerization in a batch process by in a continuous process by continuously charging at least one conjugated diolefin monomer, the functionalized monomer, and any additional monomers into a polymerization zone. The

polymerization zone will typically be a polymerization reactor or a series of polymerization reactors. The polymerization zone will normally provide agitation to keep the monomers, polymer, initiator, and modifier well dispersed throughout the organic solvent the polymerization zone. Such continuous polymerizations are typically conducted in a multiple reactor system. The rubbery polymer synthesized is continuously withdrawn from the polymerization zone. The monomer conversion attained in the polymerization zone will normally be at least about 85 percent. It is preferred for the monomer conversion to be at least about 90 percent.

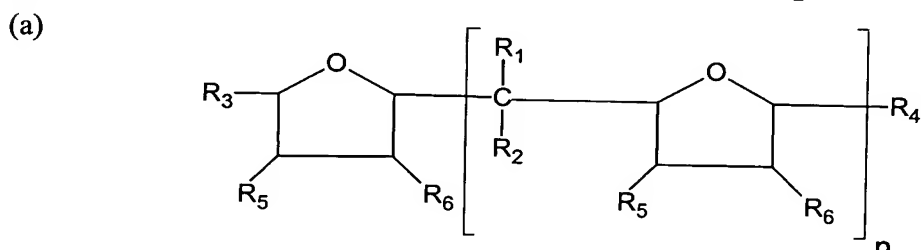
The polymerization will be initiated with an anionic initiator, such as an alkyl lithium compound, or a Zeigler-Natta catalyst. The alkyl lithium compounds that can be used will typically contain from 1 to about 8 carbon atoms, such as n-butyl lithium, The amount of the lithium initiator utilized will vary with the monomers being polymerized and with the molecular weight that is desired for the polymer being synthesized. However, as a general rule, from 0.01 to 1 phm (parts per 100 parts by weight of monomer) of the lithium initiator will be utilized. In most cases, from 0.01 to 0.1 phm of the lithium initiator will be utilized with it being preferred to utilize 0.025 to 0.07 phm of the lithium initiator.

It has been determined that it is not normally necessary to conduct the polymerizations of this invention in the presence of a conventional polar modifier. The utilization of the functionalized styrene monomer, such as PES, in the polymerization eliminates the need for a polar modifier in addition to the functionalized styrene monomer. It is accordingly not normally necessary to conduct the

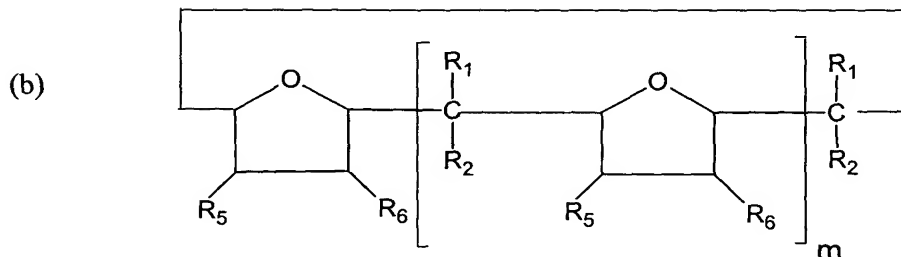
polymerization in the presence of a conventional polar modifier, such as methyltetrahydrofurfuryl ether, ethyltetrahydrofurfuryl ether, propyltetrahydrofurfuryl ether, butyltetrahydrofurfuryl ether, 5 hexyltetrahydrofurfuryl ether, octyltetrahydrofurfuryl ether, dodecyltetrahydrofurfuryl ether, diethyl ether, di-n-propyl ether, diisopropyl ether, di-n-butyl ether, tetrahydrofuran, dioxane, ethylene glycol dimethyl ether, ethylene glycol diethyl ether, diethylene glycol dimethyl 10 ether, diethylene glycol diethyl ether, triethylene glycol dimethyl ether, trimethylamine, triethylamine, N,N,N',N'-tetramethylethylenediamine, N-methyl morpholine, N-ethyl morpholine, or N-phenyl morpholine. The polymerizations of this invention that utilize functionalized styrene monomer 15 are accordingly typically conducted in the absence of conventional polar modifiers.

The polar modifier will typically be employed at a level wherein the molar ratio of the polar modifier to the lithium initiator is within the range of about 0.01:1 to 20 about 5:1. The molar ratio of the polar modifier to the lithium initiator will more typically be within the range of about 0.1:1 to about 4:1. It is generally preferred for the molar ratio of polar modifier to the lithium initiator to be within the range of about 0.25:1 to about 3:1. It is 25 generally most preferred for the molar ratio of polar modifier to the lithium initiator to be within the range of about 0.5:1 to about 3:2.

The polymerization can optionally be conducted utilizing an oligomeric oxolanyl alkane as the modifier. 30 Such oligomeric oxolanyl alkanes will typically be of a structural formula selected from the group consisting of:



and



wherein n represents an integer from 1 to 5, wherein m represents an integer from 3 to 5, wherein R<sub>1</sub>, R<sub>2</sub>, R<sub>3</sub>, R<sub>4</sub>, R<sub>5</sub>, and R<sub>6</sub> can be the same or different, and wherein R<sub>1</sub>, R<sub>2</sub>, R<sub>3</sub>, R<sub>4</sub>, R<sub>5</sub>, and R<sub>6</sub> represent a member selected from the group consisting of hydrogen atoms and alkyl groups containing from 1 to about 8 carbon atoms. It is typically preferred for R<sub>1</sub>, R<sub>2</sub>, R<sub>3</sub>, R<sub>4</sub>, R<sub>5</sub>, and R<sub>6</sub> represent a member selected from the group consisting of hydrogen atoms and alkyl groups containing from 1 to 4 carbon atoms.

The polymerization temperature utilized can vary over a broad range of from about -20°C to about 180°C. In most cases, a polymerization temperature within the range of about 30°C to about 125°C will be utilized. It is typically preferred for the polymerization temperature to be within the range of about 45°C to about 100°C. It is typically most preferred for the polymerization temperature to be within the range of about 60°C to about 90°C. The pressure used will normally be sufficient to maintain a substantially liquid phase under the conditions of the polymerization reaction.

The polymerization is conducted for a length of time sufficient to permit substantially complete polymerization of monomers. In other words, the polymerization is

normally carried out until high conversions of at least about 85 percent are attained. The polymerization is then terminated by the addition of an agent, such as an alcohol, a terminating agent, or a coupling agent. For example, a  
5 tin halide and/or silicon halide can be used as a coupling agent. The tin halide and/or the silicon halide are continuously added in cases where asymmetrical coupling is desired. This continuous addition of tin coupling agent and/or the silicon coupling agent is normally done in a  
10 reaction zone separate from the zone where the bulk of the polymerization is occurring. The coupling agents will normally be added in a separate reaction vessel after the desired degree of conversion has been attained. The coupling agents can be added in a hydrocarbon solution,  
15 e.g., in cyclohexane, to the polymerization admixture with suitable mixing for distribution and reaction. In other words, the coupling will typically be added only after a high degree of conversion has already been attained. For instance, the coupling agent will normally be added only  
20 after a monomer conversion of greater than about 85 percent has been realized. It will typically be preferred for the monomer conversion to reach at least about 90 percent before the coupling agent is added.

The tin halides used as coupling agents will normally  
25 be tin tetrahalides, such as tin tetrachloride, tin tetrabromide, tin tetrafluoride or tin tetraiodide. However, tin trihalides can also optionally be used. Polymers coupled with tin trihalides having a maximum of three arms. This is, of course, in contrast to polymers  
30 coupled with tin tetrahalides which have a maximum of four arms. To induce a higher level of branching, tin tetrahalides are normally preferred. As a general rule, tin tetrachloride is most preferred.

The silicon coupling agents that can be used will normally be silicon tetrahalides, such as silicon tetrachloride, silicon tetrabromide, silicon tetrafluoride or silicon tetraiodide. However, silicon trihalides can also optionally be used. Polymers coupled with silicon trihalides having a maximum of three arms. This is, of course, in contrast to polymers coupled with silicon tetrahalides which have a maximum of four arms. To induce a higher level of branching, silicon tetrahalides are normally preferred. As a general rule, silicon tetrachloride is most preferred of the silicon coupling agents.

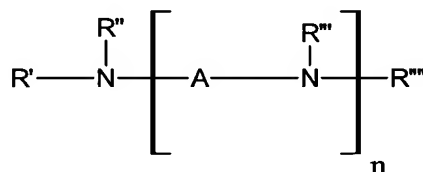
A combination of a tin halide and a silicon halide can optionally be used to couple the rubbery polymer. By using such a combination of tin and silicon coupling agents improved properties for tire rubbers, such as lower hysteresis, can be attained. It is particularly desirable to utilize a combination of tin and silicon coupling agents in tire tread compounds that contain both silica and carbon black. In such cases, the molar ratio of the tin halide to the silicon halide employed in coupling the rubbery polymer will normally be within the range of 20:80 to 95:5. The molar ratio of the tin halide to the silicon halide employed in coupling the rubbery polymer will more typically be within the range of 40:60 to 90:10. The molar ratio of the tin halide to the silicon halide employed in coupling the rubbery polymer will preferably be within the range of 60:40 to 85:15. The molar ratio of the tin halide to the silicon halide employed in coupling the rubbery polymer will most preferably be within the range of 65:35 to 80:20.

Broadly, and exemplary, a range of about 0.01 to 4.5 milliequivalents of tin coupling agent (tin halide and

silicon halide) is employed per 100 grams of the rubbery polymer. It is normally preferred to utilize about 0.01 to about 1.5 milliequivalents of the coupling agent per 100 grams of polymer to obtain the desired Mooney viscosity.

5 The larger quantities tend to result in production of polymers containing terminally reactive groups or insufficient coupling. One equivalent of tin coupling agent per equivalent of lithium is considered an optimum amount for maximum branching. For instance, if a mixture  
10 tin tetrahalide and silicon tetrahalide is used as the coupling agent, one mole of the coupling agent would be utilized per four moles of live lithium ends. In cases where a mixture of tin trihalide and silicon trihalide is used as the coupling agent, one mole of the coupling agent  
15 will optimally be utilized for every three moles of live lithium ends. The coupling agent can be added in a hydrocarbon solution, e.g., in cyclohexane, to the polymerization admixture in the reactor with suitable mixing for distribution and reaction.

20 After the coupling has been completed, a tertiary chelating alkyl 1,2-ethylene diamine or a metal salt of a cyclic alcohol can optionally be added to the polymer cement to stabilize the coupled rubbery polymer. The tertiary chelating amines that can be used are normally  
25 chelating alkyl diamines of the structural formula:



30

wherein n represents an integer from 1 to about 6, wherein A represents an alkylene group containing from 1 to about 6 carbon atoms and wherein R', R'', R''' and R'''' can be the



same or different and represent alkyl groups containing from 1 to about 6 carbon atoms. The alkylene group A is of the formula  $-(\text{CH}_2)_m$  wherein m is an integer from 1 to about 6. The alkylene group will typically contain from 1 to 4 carbon atoms (m will be 1 to 4) and will preferably contain 2 carbon atoms. In most cases, n will be an integer from 1 to about 3 with it being preferred for n to be 1. It is preferred for R', R'', R''' and R'''' to represent alkyl groups which contain from 1 to 3 carbon atoms. In most cases, R', R'', R''' and R'''' will represent methyl groups.

In most cases, from about 0.01 phr (parts by weight per 100 parts by weight of dry rubber) to about 2 phr of the chelating alkyl 1,2-ethylene diamine or metal salt of the cyclic alcohol will be added to the polymer cement to stabilize the rubbery polymer. Typically, from about 0.05 phr to about 1 phr of the chelating alkyl 1,2-ethylene diamine or metal salt of the cyclic alcohol will be added. More typically, from about 0.1 phr to about 0.6 phr of the chelating alkyl 1,2-ethylene diamine or the metal salt of the cyclic alcohol will be added to the polymer cement to stabilize the rubbery polymer.

The terminating agents that can be used to stop the polymerization and to "terminate" the living rubbery polymer include tin monohalides, silicon monohalides, N,N,N',N'-tetradialkyldiamino-benzophenones (such as tetramethyldiaminobenzophenone and the like), N,N-dialkylamino-benzaldehydes (such as dimethylaminobenzaldehyde and the like), 1,3-dialkyl-2-imidazolidinones (such as 1,3-dimethyl-2-imidazolidinone and the like), 1-alkyl substituted pyrrolidinones; 1-aryl substituted pyrrolidinones, dialkyl- dicycloalkyl-carbodiimides containing from about 5 to about 20 carbon

atoms, and dicycloalkyl-carbodiimides containing from about 5 to about 20 carbon atoms.

After the termination step, and optionally the stabilization step, has been completed, the rubbery polymer can be recovered from the organic solvent. The coupled rubbery polymer can be recovered from the organic solvent and residue by means such as chemical (alcohol) coagulation, thermal desolventization, or other suitable method. For instance, it is often desirable to precipitate the rubbery polymer from the organic solvent by the addition of lower alcohols containing from 1 to about 4 carbon atoms to the polymer solution. Suitable lower alcohols for precipitation of the rubber from the polymer cement include methanol, ethanol, isopropyl alcohol, normal-propyl alcohol and t-butyl alcohol. The utilization of lower alcohols to precipitate the rubbery polymer from the polymer cement also "terminates" any remaining living polymer by inactivating lithium end groups. After the coupled rubbery polymer is recovered from the solution, steam-stripping can be employed to reduce the level of volatile organic compounds in the coupled rubbery polymer. Additionally, the organic solvent can be removed from the rubbery polymer by drum drying, extruder drying, vacuum drying, and the like.

The polymers of the present invention can be used alone or in combination with other elastomers to prepare an rubber compounds, such as a tire treadstock, sidewall stock or other tire component stock compounds. In a tire of the invention, at least one such component is produced from a vulcanizable elastomeric or rubber composition. For example, the rubbery polymer made by the process of this invention can be blended with any conventionally employed treadstock rubber which includes natural rubber, synthetic

rubber and blends thereof. Such rubbers are well known to those skilled in the art and include synthetic polyisoprene rubber, styrene/butadiene rubber (SBR), polybutadiene, butyl rubber, Neoprene, ethylene/propylene rubber,  
5 ethylene/propylene/diene rubber (EPDM), acrylonitrile/butadiene rubber (NBR), silicone rubber, the fluoroelastomers, ethylene acrylic rubber, ethylene vinyl acetate copolymer (EVA), epichlorohydrin rubbers, chlorinated polyethylene rubbers, chlorosulfonated  
10 polyethylene rubbers, hydrogenated nitrile rubber, tetrafluoroethylene/propylene rubber and the like.

When the rubbery polymers made by the process of the present invention are blended with conventional rubbers, the amounts can vary widely such as between 10 and 99  
15 percent by weight. In any case, tires made with synthetic rubbers that are synthesized utilizing the technique of this invention exhibit decreased rolling resistance. The greatest benefits are realized in cases where the tire tread compound is made with the rubbery polymer synthesized  
20 utilizing the technique of this invention. However, benefits can also be attained in cases where at least one structural element of the tire, such as subread, sidewalls, body ply skim, or bead filler, is comprised of the rubbery.

25 The synthetic rubbers made in accordance with this invention can be compounded with carbon black in amounts ranging from about 5 to about 100 phr (parts by weight per 100 parts by weight of rubber), with about 5 to about 80 phr being preferred, and with about 40 to about 70 phr  
30 being more preferred. The carbon blacks may include any of the commonly available, commercially-produced carbon blacks but those having a surface area (EMSA) of at least 20 m<sup>2</sup>/g and more preferably at least 35 m<sup>2</sup>/g up to 200 m<sup>2</sup>/g or

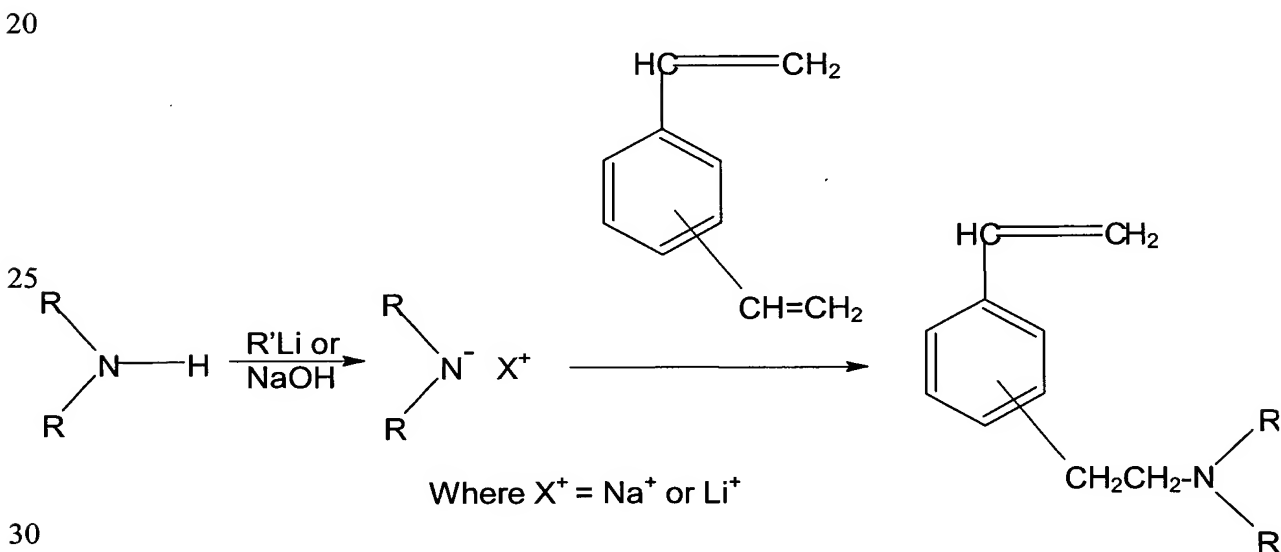
higher are preferred. Surface area values used in this application are those determined by ASTM test D-1765 using the cetyltrimethyl-ammonium bromide (CTAB) technique. Among the useful carbon blacks are furnace black, channel blacks and lamp blacks. More specifically, examples of the carbon blacks include super abrasion furnace (SAF) blacks, high abrasion furnace (HAF) blacks, fast extrusion furnace (FEF) blacks, fine furnace (FF) blacks, intermediate super abrasion furnace (ISAF) blacks, semi-reinforcing furnace (SRF) blacks, medium processing channel blacks, hard processing channel blacks and conducting channel blacks. Other carbon blacks which may be utilized include acetylene blacks. Mixtures of two or more of the above blacks can be used in preparing the carbon black products of the invention. Typical values for surface areas of usable carbon blacks are summarized in the following table.

<u>Carbon Black</u>		
	<u>ASTM Designation (D-1765-82a)</u>	<u>Surface Area (D-3765)</u>
20	N-110	126 m <sup>2</sup> /g
	N-220	111 m <sup>2</sup> /g
	N-330	83 m <sup>2</sup> /g
	N-339	95 m <sup>2</sup> /g
	N-550	42 m <sup>2</sup> /g
25	N-660	35 m <sup>2</sup> /g

The carbon blacks utilized in the preparation of rubber compounds may be in pelletized form or an unpelletized flocculent mass. Preferably, for more uniform mixing, unpelletized carbon black is preferred. The reinforced rubber compounds can be cured in a conventional manner with about 0.5 to about 4 phr of known vulcanizing agents. For example, sulfur or peroxide-based curing

systems may be employed. For a general disclosure of suitable vulcanizing agents one can refer to Kirk-Othmer, Encyclopedia of Chemical Technology, 3rd ed., Wiley Interscience, N.Y. 1982, Vol. 20, pp. 365-468, particularly  
 5 "Vulcanization Agents and Auxiliary Materials" pp. 390-402. Vulcanizing agents can, of course, be used alone or in combination. Vulcanizable elastomeric or rubber compositions can be prepared by compounding or mixing the polymers thereof with carbon black and other conventional  
 10 rubber additives such as fillers, plasticizers, antioxidants, curing agents and the like, using standard rubber mixing equipment and procedures and conventional amounts of such additives.

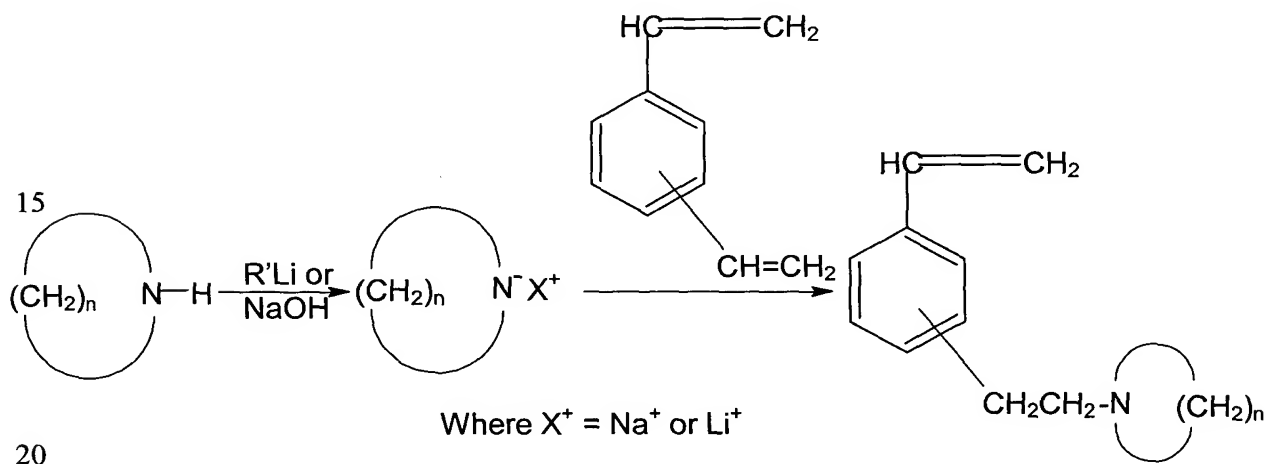
The functionalized styrene monomer can be synthesized  
 15 by (1) reacting a secondary amine with an organolithium compound to produce a lithium amide, and (2) reacting the lithium amide with divinylbenzene or diisopropenyl benzene to produce the functionalized styrene monomer. This procedure can be depicted as follows:



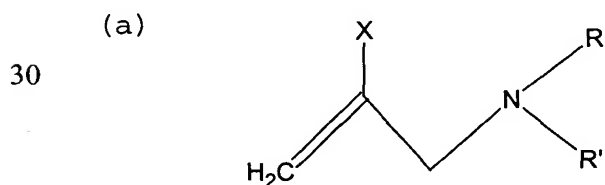
A process for synthesizing an amino ethyl styrene monomer which comprises: (1) reacting divinyl benzene with a cyclic amine in a reacting mixture in the presence of an

alkyl lithium compound at a temperature which is within the range of  $-80^{\circ}\text{C}$  to  $80^{\circ}\text{C}$  to produce the amino ethyl styrene; and (2) deactivating the alkyl lithium compound by adding an alcohol or water to the reaction mixture containing the amino ethyl styrene.

Functionalized monomers that contain cyclic amines can also be made by the same reaction scheme wherein a cyclic secondary amine is employed in the first step of the reaction. This reaction scheme can be depicted as follows:



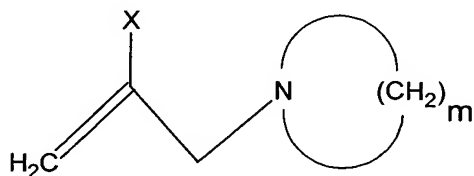
In another embodiment of this invention a functionalized monomer can be synthesized by a process that comprises (1) reacting a secondary amine with a 2,3-dihalopropene to produce a vinyl halide containing secondary amine having a structural formula selected from the group consisting of



wherein R and R' can be the same or different and represent allyl, alkoxyl or alkyl groups containing from 1 to about 10 carbon atoms, and wherein X represents a halogen atom, and

5

(b)

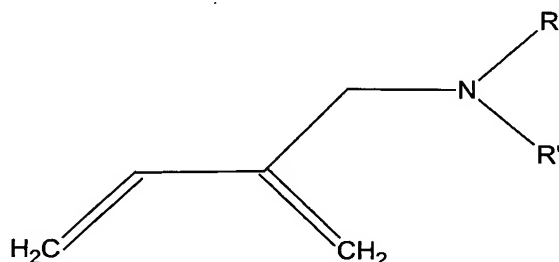


10

wherein m represents an integer from 4 to about 10, and wherein X represents a halogen atom; and (2) reacting the vinyl halide containing secondary amine with a vinyl magnesium halide to produce the monomer, wherein the monomer has a structural formula selected from the group consisting of

15

(a)

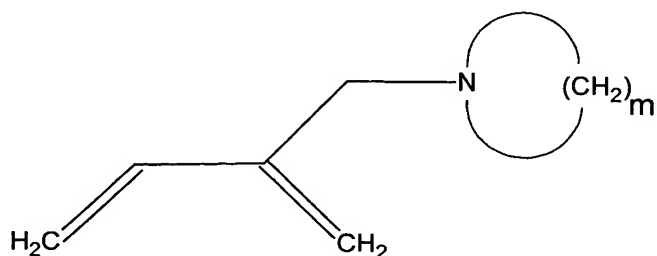


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wherein R and R' can be the same or different and represent allyl, alkoxyl or alkyl groups containing from 1 to about 10 carbon atoms, and

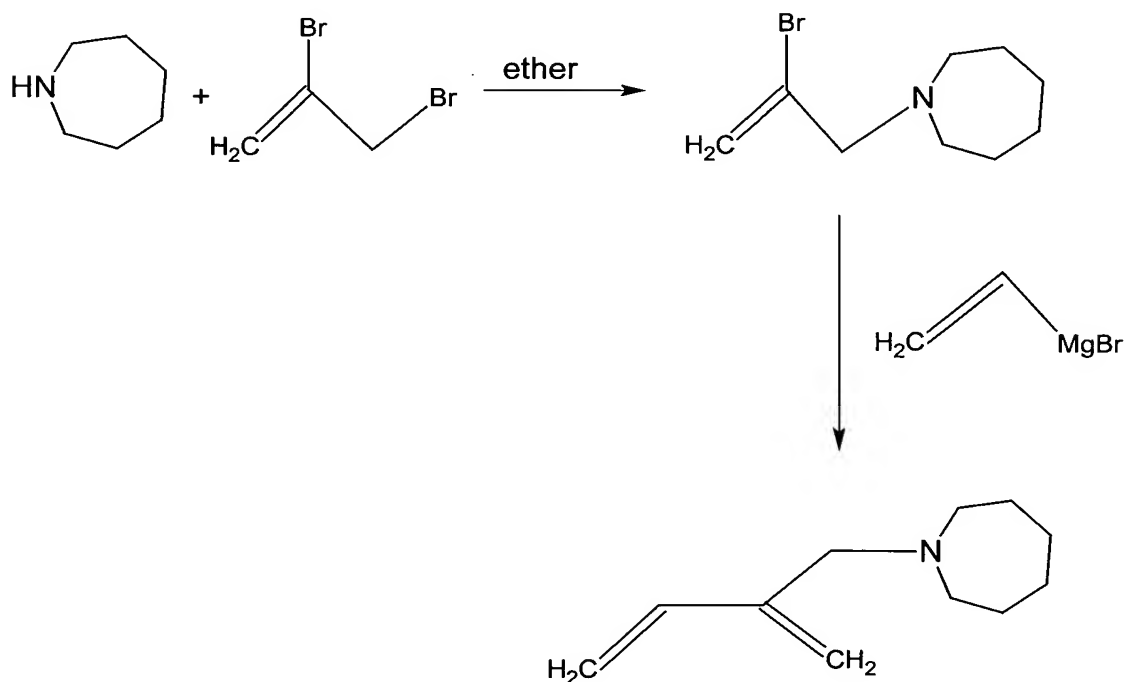
25

(b)



30

wherein m represents an integer from about 4 to about 10.  
Such a reaction scheme can be depicted as follows:



5            In the first step of this reaction scheme a secondary  
cyclic amine is reacted with a 2,3-dihalopropene (2,3-  
bromopropene is shown above). This step is typically  
conducted in an organic solvent, such as diethyl ether, at  
a temperature which is within the range of about -20°C to  
10    about 60°C, and is preferable conducted at a temperature  
which is within the range of 0°C to about 30°C. As can be  
seen this results in the production of a vinyl halide  
containing secondary amine.

15           In the second step of the process the vinyl halide  
containing secondary amine is reacted with a vinyl  
magnesium halide to produce the functionalized monomer.  
The second step is conducted in a polar organic solvent,  
such as tetrahydrofuran or diethyl ether. The second step  
is also conducted at a temperature that is within the range



of about -20°C to about 60°C, and is preferable conducted at a temperature which is within the range of 0°C to about 30°C.

This invention is illustrated by the following examples that are merely for the purpose of illustration and are not to be regarded as limiting the scope of the invention or the manner in which it can be practiced. Unless specifically indicated otherwise, parts and percentages are given by weight.

#### Example 1

In this experiment 2-(N-hexamethyleneimino)-methyl 1,3-butadiene was synthesized utilizing the technique of this invention. In the procedure used a solution of 2,3-dibromopropane (0.1 mol) in ethyl ether was slowly added to a solution of hexamethyleneimine (0.4 mol) in ethyl ether at 0°C. The reaction mixture was stirred overnight at room temperature. The next day a 1M NaOH solution was added to quench the mixture and the organic layer was collected using a separatory funnel and extracted with diethyl ether. The organic layer was subsequently washed with water two times. After drying with sodium sulfate, the filtrate was evaporated and the resulting residue was distilled to yield 2-bromo-3-(N-hexamethyleneimino)propene. The boiling point and yield of the product were determined to be 65-68°C at 30 mm-Hg. The yield was determined to be 60%. The molecular structure of 2-bromo-3-(N-hexamethylene-imino)propene was verified by proton NMR.

Vinyl magnesium bromide in tetrahydrofuran (THF; 0.085 mol) was added dropwise to a flask containing the 2-bromo-3-(N-hexamethylene-imino)propene (0.056 mol) in the presence of [1,3-bis(diphenylphosphino) propane]

dichloronickel(II) (0.21 mol) at 0°C. After stirring for 24 hours at room temperature, the hydrolysis of the reaction mixture by saturated ammonium chloride solution was carried out and followed by extraction with diethyl ethyl three times. The organic material was dried by sodium sulfate and then filtered. After evaporating the solvent, the residue was distilled to give a colorless liquid of 2-(N-hexa-methyleneimino)-methyl 1,3-butadiene. The boiling point and yield were -114°C at 30 mm-Hg and 60%, respectively. The molecular structure of the resulting product was verified by proton NMR.

#### Example 2

The preparation of 2-(N,N-diethylamino)-methyl-1,3-butadiene is described in this example. The procedure described in Example 1 was utilized except that N,N-diethylamine was used in place of hexamethyleneimine. The yield for the intermediate product, 2-bromo-3-(N,N-diethylamino)propene was 98%. The boiling point and yield of the final product, 2-(N,N-diethylamino)-methyl-1,3-butadiene was determined to be 112-114°C at 30 mm-Hg and 50%, respectively.

#### Examples 3-5

In these experiments 2-(N-pyrrolidino)-methyl-1,3-butadiene, 2-(N-morpholino)-methyl-1,3-butadiene, and 2-(N-piperidino)-methyl-1,3-butadiene were synthesized utilizing a procedure that is similar to the one described in Example 1 except that pyrrolidine, morpholine and piperidine were used in place of the hexamethyleneimine.

#### Example 6

In this experiment, a 25/75 SBR containing 1% of

hexamethyleneimine (HMI) functional groups was prepared. 2350 g of a silica/alumina/molecular sieve dried premix containing 19.50 weight percent styrene and 1,3-butadiene in hexanes was charged into a one-gallon (3.8 liters) reactor. The styrene to 1,3-butadiene ratio was 25:75. 4.6 grams of a neat 2-(N-hexamethyleneimino)-methyl 1,3-butadiene was added to the reactor. Then, 2.9 ml of 1 M solution of N,N,N',N'-tetramethylethylenediamine (TMEDA) and 2.3 ml of 1.6 M n-butyl lithium (n-BuLi) in hexanes were added to the reactor, respectively. The polymerization was carried out at 70°C for 90 minutes. The GC analysis of the residual monomer contained in the polymerization mixture indicated that the all monomers were consumed at this time, the polymer cement was then shortstopped with ethanol and then removed from the reactor and stabilized with 1 phm of antioxidant. After evaporating hexanes, the resulting polymer was dried in a vacuum oven at 50°C.

The styrene-butadiene rubber (SBR) produced was determined to have a glass transition temperature (Tg) at -33°C. It was also determined to have a microstructure which contained 41 percent 1,2-polybutadiene units, 34 percent 1,4-polybutadiene units and 25 percent random polystyrene units. It also contained about 1 weight percent of HMI units. The Mooney viscosity (ML-4) at 100°C for this SBR was determined to be 27. The GPC data of this polymer was also determined to have a Mn of 129,000 and Mw of 136,000. The polydispersity (Mw/Mn) was 1.05. The HMI functionality of the resulting SBR was verified via a HPLC-GPEC (Gradient polymer elution chromatography) method using Novapak C18 column using a mixture of acetonitrile/THF as solvent. As determined by GPEC method, 93% of this polymer contains HMI functional groups.

Examples 7-8

In these examples, 25/75 SBRs containing 0.25 and 0.5 weight percent of 2-(N-hexamethyleneimino)-methyl 1,3-butadiene were prepared using the procedures described in Example 6 except that 1.2 and 2.3 grams of 2-(N-hexamethyleneimino)-methyl 1,3-butadiene, respectively were added to the premix prior to polymerization. The characterization data of these two polymers are listed in Table 1.

Example 9

In the example, a tin coupled 25/75 SBR containing 0.5 weight percent of 2-(N-hexamethyleneimino)-methyl 1,3-butadiene was prepared. 2350 g of a silica/alumina/molecular sieve dried premix containing 19.50 weight percent styrene and 1,3-butadiene in hexanes was charged into a one-gallon (3.8 liters) reactor. The styrene to 1,3-butadiene ratio was 25:75. 2.3 grams of a neat 2-(N-hexamethyleneimino)-methyl 1,3-butadiene was added to the reactor. 2.9 ml of 1 M solution of N,N,N',N'-tetramethylethylenediamine (TMEDA) and 2.3 ml of 1.6 M n-butyl lithium (n-BuLi) in hexanes were added to the reactor, respectively. The polymerization was carried out at 70 °C for 90 minutes. The GC analysis of the residual monomer contained in the polymerization mixture indicated that the all monomers were consumed at this time. 0.9 ml of a 1 M solution of tin tetrachloride in hexanes was then added to the polymerization mixture. The coupling reaction was allowed to proceed at 70°C for 30 minutes. The coupling efficiency was 69%. The characterization data of this coupled and HMI functionalized polymer are also listed in Table 1.

### Comparative Example 10

In this example, a control 25/75 SBR containing 0 weight percent of 2-(N-hexamethyleneimino)-methyl 1,3-butadiene was prepared using the procedures described in Example 6 except no 2-(N-hexamethyleneimino)-methyl 1,3-butadiene was used. The characterization data of this polymer are also included in Table 1.

TABLE 1

Example No.	wt % HMI-Monomer	Coupler	Tg (°C)	ML-4	Mn	Mw	Mw/Mn
10	0	None	-33	23	137,000	139,000	1.02
	0.25	None	-36	21	126,000	128,000	1.01
15	0.50	None	-32	27	139,000	142,000	1.03
	1.00	None	-33	27	129,000	136,000	1.05
	0.50	SnCl4	-32	83	677,000	812,000	1.20 (42%)
					329,000	335,000	1.02 (27%)
					145,000	155,000	1.06 (31%)

### Example 11

In this example, a 25/75 SBR containing 0.5 weight percent of 2-(N-hexamethyleneimino)-methyl 1,3-butadiene was prepared using the procedures described in Example 6 except that 2.3 grams of 2-(N-hexamethyleneimino)-methyl 1,3-butadiene was pre-reacted with n-BuLi in the presence of TMEDA. The pre-reacted n-BuLi containing HMI functional groups was then used as the catalyst to initiate the polymerization. The characterization data of this polymer are listed in Table 2.

### Examples 12-13

In these examples, 25/75 SBRs containing 0.1 and 0.25% weight percent of 2-(N-hexamethyleneimino)-methyl 1,3-butadiene were prepared using the procedures described in Example 11 except that 0.5 and 1.2 grams of 2-(N-hexamethyleneimino)-methyl 1,3-butadiene were pre-reacted with n-BuLi in the presence of TMEDA. The characterization

data of this polymer are listed in Table 2.

Example 14

In this example, a 25/75 SBR containing 0.5 weight  
5 percent of 2-(N-hexamethyleneimino)-methyl 1,3-butadiene  
were prepared using the procedures described in Example 6  
except that 4.6 grams of 2-(N-hexamethyleneimino)-methyl  
1,3-butadiene was diluted with 10.8 ml of dried hexane and  
added sequentially in 5 equal portions (3 ml each) to the  
10 polymerization mixture at 0, 5, 15, 30 and 90 minutes time  
periods. The total polymerization time was 100 minutes.  
The characterization data of this polymer are listed in  
Table 2.

15 Examples 15-16

In these examples, 25/75 SBRs containing 0.1 and 0.25  
weight percent of 2-(N-hexamethyleneimino)-methyl 1,3-  
butadiene were prepared using the procedures described in  
Example 14 except that 0.5 and 1.2 grams of 2-(N-  
20 hexamethyleneimino)-methyl 1,3-butadiene were added  
sequentially to the polymerization mixture as indicated in  
Example 14. The characterization data of this polymer are  
listed in Table 2.

25 Example 17

In this example, a 25/75 SBR containing 0.25 weight  
percent of 2-(N-hexamethyleneimino)-methyl 1,3-butadiene  
was prepared using the procedures described in Example 6  
except that 1.2 grams of 2-(N-hexamethyleneimino)-methyl  
30 1,3-butadiene was added to the polymerization mixture at  
the end of polymerization (90 minutes). The polymerization  
was continued for another 30 minutes at 70°C. The  
characterization data of this polymer are listed in Table

2.

TABLE 2

5	Example No.	wt % HMI-Monomer	Mode of HMI-Monomer addition	Tg (°C)	ML-4	GPC		
						Mn	Mw	Mw/Mn
10	7	0.25	initial charge	-36	21	126,000	128,000	1.01
	8	0.50	initial charge	-32	27	139,000	142,000	1.03
	6	1.00	initial charge	-33	27	129,000	136,000	1.05
	11	0.50	pre-reacted	-33	27	133,900	136,300	1.02
	12	0.10	pre-reacted	-33	26	136,600	138,800	1.02
	13	0.25	pre-reacted	-37	24	129,000	136,000	1.02
	14	0.50	sequential	-36	21	81,600	86,730	1.06 (50%)
15						212,000	235,600	1.11 (50%)
	15	0.10	sequential	-35	25	115,900	121,300	1.05 (80%)
						257,600	265,200	1.03 (20%)
20	16	0.25	sequential	-33	24	95,800	100,000	1.04 (57%)
						227,000	245,200	1.08 (43%)
	17	0.25	end charge	-33	29	138,400	140,200	1.01

Comparative Example 18

25 In this example, a 25/75 SBR containing 2% of pyrrolidine functional groups was prepared via co-polymerizing styrene/1,3-butadiene monomers with 4-(N-pyrrolidinomethyl) styrene. The procedure described in example 6 was employed except that 9.2 grams of a neat 4-

30 (N-pyrrolidinomethyl) styrene was used instead of 2-(N-hexamethyleneimino)-methyl 1,3-butadiene. Based on GC analysis of the residual monomer, the polymerization was also completed in 90 minutes at 70°C. The GC data also indicated that 4-(N-pyrrolidinomethyl) styrene was randomly

35 distributed along the polymer chains. The styrene-butadiene rubber (SBR) produced was determined to have a glass transition temperature (Tg) at -30°C. It was also determined to have a microstructure which contained 42 percent 1,2-polybutadiene units, 32 percent

40 1,4-polybutadiene units, 24 percent random polystyrene units and 2% 4-(N-pyrrolidino-methyl) styrene units. The

Mooney viscosity (ML-4) at 100°C for this SBR was determined to be 27. The GPC data of this polymer was also determined to have a Mn of 131,000 and Mw of 134,000. The polydispersity (Mw/Mn) was 1.02

5

#### Comparative Examples 19-20

In these examples, 25/75 SBRs containing 2 weight percent of HMI and piperidine functional groups were prepared using the procedures described in Example 18 except that 4-(N-hexamethyleneiminomethyl) styrene and 4-(N-piperidinomethyl) styrene, in place of 4-(N-pyrrolidinomethyl) styrene, were added to the premix, respectively prior to polymerization. The Tg and ML-4 of these two amine functionalized SBRs were -30°C, 26 and -31°C, 28, respectively.

15

#### Example 21

In this example, a 25/75 SBRs containing 1 weight percent of di-allylamine functional groups was prepared using the procedures described in Example 18 except that 4-(N-diallylaminomethyl) styrene was used instead of 4-(N-pyrrolidinomethyl) styrene. The polymer was determined to have a Tg at -40°C.

20

#### Example 22

25

In this experiment, a high trans 10/90 SBR containing 0.5% pyrrolidine functional groups was prepared. 2150 g of a silica/alumina/molecular sieve dried premix containing 19.50 weight percent styrene/1,3-butadiene in hexane was charged into a one-gallon (3.8 liters) reactor. 2.1 grams of 2-(N-hexamethylene-imino)-methyl 1,3-butadiene was also added to the reactor. 20 ml of a 0.172 M pre-alkylated barium catalyst (prepared by reacting one mole of barium

30



salt of di(ethylene glycol)ethylether (BaDEGEE) in ethylbenzene with 4 moles tri-n-octylaluminum (TOA) in hexanes at 70°C) and 7 ml of 1.6 M solution of n-butyllithium (n-BuLi) in hexanes were added to the reactor

5 The polymerization was carried out at 100°C for 3 hours. The GC analysis of the residual monomer contained in the polymerization mixture indicated that the total monomer conversions 96% and disappearance of 2-(N-hexamethylene-imino)-methyl 1,3-butadiene monomer. One ml of neat ethanol

10 was added to shortstop the polymerization. The polymer cement was then removed from the reactor and stabilized with 1 phm of antioxidant. After evaporating hexanes, the resulting polymer was dried in a vacuum oven at 50°C.

The HTSBR produced was determined to have a glass

15 transition temperature (T<sub>g</sub>) at -83°C and a melting temperature, T<sub>m</sub> at 17°C. It was then determined to have a microstructure which contained 3.5 percent 1,2-polybutadiene units, 14.4 percent cis-1,4-polybutadiene units 74.5% trans-1,4-polybutadiene units and 7.6%

20 polystyrene. Both NMR and GPEC indicated the presence of HMI functional groups.

The Mooney viscosity (ML-4) at 100 °C for this polymer was determined to be 98. The GPC measurements indicated that the polymer has a number average molecular weight (M<sub>n</sub>)

25 of 107,5000 and a weight average molecular weight (M<sub>w</sub>) of 187,30,000. The polydispersity (M<sub>w</sub>/M<sub>n</sub>) of the resulting polymer is 1.74.

#### Examples 23-24

30 In these examples, high trans polybutadiene and SBR containing 1.0 weight percent of pyrrolidine functional groups were prepared by using 4-(N-pyrrolidinomethyl)styrene as a comonomer. The procedures

described in Example 22 were used in these examples except that 1,3-butadiene was used as the main monomer in Example 23. And, 4-(N-pyrrolidinomethyl)styrene was used instead of 2-(N-hexamethylene-imino)-methyl 1,3-butadiene. The polymerization was conducted at 70°C for 4 hours. The polymer characterization data of these polymers are listed in Table 3.

Table 3

Example No	Polymer	% pyrrolidine	Tg (°C)	Tm (°C)	Mn	GPC Mw	Mw/Mn
23	HTPBD	1.0	-90	35, 45, 59	83,400	100,500	1.21
24	HTSBR	1.0	-84	27, 39	69,540	81,300	1.17

Example 25

In this example, a cis-1,4- polybutadiene containing 0.5 weight percent of 2-(N-hexamethyleneimino)-methyl 1,3-butadiene was prepared in a bottle using a catalyst consisting of neodymium neodecanoate/ tri-n-octylaluminum/t-butylchloride, at a 1/10/2 molar ratio, at 70 °C for 1 hours. GC analysis of residual monomer showed the polymerization was completed. 2-(N-hexamethyleneimino)-methyl 1,3-butadiene also was consumed. The polybutadiene produced was determined to have a glass transition temperature (Tg) at - 111 °C and a melting peak at -6°C. It was also determined to have a microstructure which contained 0.7 percent 1,2-polybutadiene units, 99.3 percent 1,4-polybutadiene units. The polymer was also determined to have a Mn of 324,000 and a Mw of 815,000. The polydispersity (Mw/Mn) was 2.51. The presence of HMI functional groups was also verified by GPEC method.

Example 26

In this example, a cis-1,4- polyisoprene containing 0.5 weight percent of 2-(N-hexamethyleneimino)-methyl 1,3-butadiene was prepared in a bottle using a catalyst  
5 consisting of neodymium neodecanoate/ tri-n-octylaluminum/t-butylchloride, at a 1/10/2 molar ratio, at 70°C for 2 hours. GC analysis of residual monomer showed the polymerization was completed. 2-(N-hexamethyleneimino)-methyl 1,3-butadiene also was consumed. The polyisoprene  
10 produced was determined to have a glass transition temperature (Tg) at -67°C. The polymer was also determined to have a Mn of 497,000 and a Mw of 1,207,000. The polydispersity (Mw/Mn) was 2.42. The presence of HMI functional groups was also verified by NMR and GPEC  
15 techniques.

Comparative Example 27

One mole of neat piperidine was added under nitrogen to a round bottom flask containing 500 ml of 20-35% aqueous  
20 sodium hydroxide. The round bottom flask was equipped with a mechanical stirrer. The mixture was then cooled to 40°F and one mole of 4-vinyl benzyl chloride or a mixture of 3-vinyl benzyl chloride and 4-vinyl benzyl chloride was added drop-by-drop to the mixture for a period of 30-60 minutes  
25 at a temperature of 40°F to 50°F. Upon completion of the addition, the reaction mixture was heated to room temperature with the stirring being continued for a period of 2 to 4 hours. The reaction mixture was then extracted with toluene or diethyl ether. The organic filtrate was  
30 then dried over potassium hydroxide (KOH) pellets.

The toluene or diethyl ether was then removed from the dried filtrate using a rotary evaporator under reduced pressure. The neat pyrrolidinomethyl styrene was then

recovered by vacuum distillation. The boiling points of the mixture of 3-N-piperidinomethyl styrene and 4-N-piperidinomethyl styrene was 115-120°C at 0.5 mm-Hg. The yield was about 70 percent.

5 By utilizing a similar procedure 4-N-hexamethylene iminomethyl styrene, 4-N-pyrrolidino methyl styrene, and 4-N-dialkyl amino styrene or mixtures of 3-isomers and 4-isomers can be prepared.

10 Comparative Examples 28-32

In this series of experiments the rubber samples made in Examples 6-10 were compounded with 55 phr (parts by weight per 100 parts by weight of rubber) of carbon black and cured. The physical properties of the compounded  
15 rubber samples are shown Table 4.

Table 4

Example	Rubber from Example No.	Percent Functionalized Monomer	Uncured G' (15% @ 0.83 Hz)	Cured G' (5% @ 1Hz)	Cured tan delta (5% @ 1 Hz)
28	10	0.0	142 kPa	2.0 MPa	0.178
29	7	0.25	192 kPa	1.6 MPa	0.113
30	8	0.50	242 kPa	1.8 MPa	0.122
31	6	1.0	281 kPa	1.5 MPa	0.119
32	9	0.5*	405 kPa	1.6 MPa	0.097

\* The rubber was also coupled with tin tetrachloride  
20 (SnCl<sub>4</sub>).

This series of experiments shows that the solution elastomer compositions with functionalized monomers exhibited increased uncured viscosity (G' at 15% strain) indicating the presence of strong interactions between  
25 polymer and filler. The composition with functional

comonomer also showed significantly reduced tan delta values indicating that improved rolling resistance would be realized if the rubber was used in tire tread compounds.

5

Example 33

In this experiment 3-(2-pyrrolidinoethyl) and 4-(2-pyrrolidinoethyl) styrene were synthesized. In the procedure used 1030 grams of 80% divinylbenzene (824 grams of pure divinylbenzene 6.324 moles; the ratio of meta-DVB to para-DVB was normally 60:40) was added under nitrogen to a 5 liter flask equipped with a stirrer that contained 2 liters of dry hexane. To this homogenous solution was added 6.239 moles (450 g or 528 ml of dry pyrrolidine). This homogenous solution was cooled with wet/ice acetone to -5°C. At this temperature, 2.5% of the 6329 mmoles which is 155.9 mmoles of n-butyllithium was added all at once. The reaction temperatures rose to +55°C. The reaction was allowed to cool to +5°C for one hour. After that the reaction was neutralized with distilled water and three samples were taken for gas chromatography (GC) analysis.

After drying the reaction mixture with magnesium sulfate, the hexane in the filtrate was evaporated and the resulting residue was distilled at reduced pressure to yield a mixture of 3 and 4-(2-pyrrolidinoethyl)styrene. The boiling point was 105-110°C at 0.3 mm-Hg. The product contained 96% of a mixture of 3-(2-pyrrolidinoethyl)styrene and 4-(2-pyrrolidinoethyl) styrene and 4% of a mixture of 3-(2-pyrrolidinoethyl) styrene and 4-(2-pyrrolidinoethyl)-1-ethylbenzene as determined by proton NMR in CDCl<sub>3</sub>. The ratio of 3-(2-pyrrolidinoethyl)styrene to 4-(2-pyrrolidinoethyl)styrene was normally 60:40.

Example 34

In this experiment, a 2/18/80 pyrrolidinoethylstyrene/  
styrene/1,3-butadiene terpolymer was prepared. In the  
procedure used, 2068 grams of a silica/alumina/molecular  
5 sieve dried premix containing 20.14 weight percent of  
pyrrolidinoethyl styrene, styrene and 1,3-butadiene in  
hexane was charged into a one-gallon (3.8 liters) reactor.  
The pyrrolidinoethylstyrene (PES) used contained a mixture  
of 3-(2-pyrrolidinoethyl) styrene and 4-(2-  
10 pyrrolidinoethyl) styrene and a small amount of mixed 3-(2-  
pyrrolidinoethyl)-1-ethylbenzene and 4-(2-  
pyrrolidinoethyl)-1-ethylbenzene. The ratio of 3-(2-  
pyrrolidinoethyl) styrene to 4-(2-pyrrolidinoethyl)styrene  
could be varied, although it was normally 60:40. The ratio  
15 of PES to styrene to 1,3-butadiene ratio was 2:18:80.  
Then, 0.48 ml of neat N,N,N',N'-tetramethylethylenediamine  
(TMEDA) and 1.5 ml of 1.6 M n-butyl lithium (n-BuLi) in  
hexanes solvent were added to the reactor. The molar ratio  
of TMEDA to n-BuLi was 1.5:1. The polymerization was  
20 carried out at a temperature of 70°C for 90 minutes. A GC  
analysis of the residual monomer contained in the  
polymerization mixture indicated that the all monomers had  
been consumed by this time. The polymer cement was then  
shortstopped with ethanol and removed from the reactor and  
25 stabilized with 1 phm of antioxidant. After evaporating  
hexane, the resulting polymer was dried in a vacuum oven at  
50°C. The GC analysis of the residual monomer with respect  
to the polymerization time also indicated that PES was  
randomly distributed along the polymer chain.  
30 The PES-styrene-butadiene terpolymer produced was  
determined to have a glass transition temperature (T<sub>g</sub>) at  
- 34°C. It was also determined to have a microstructure  
which contained 48.0 percent 1,2-polybutadiene units, 32.9

percent 1,4-polybutadiene units, 17.4 percent random polystyrene units and 1.7 percent of PES units. The Mooney viscosity (ML-4) at 100°C for this polymer was determined to be 42. The GPC data of this polymer was also determined to have a number average molecular weight (Mn) of 181,900 and weight average molecular weight (Mw) of 190,700. The polydispersity (Mw/Mn) of the polymer was 1.05.

Other PES-styrene-butadiene terpolymers containing 0.25, 0.5, 1.0 and 5.0 weight percent PES having similar glass transition temperatures within the range of -32°C to -37°C were prepared similarly for compound evaluation.

#### Comparative Example 35

In this example, a 2/18/80 pyrrolidinomethylstyrene/styrene/1,3-butadiene terpolymer was prepared using the procedures described in Example 34 except that pyrrolidinomethyl styrene (PMS) was used instead of PES. The PMS was prepared from vinylbenzylchloride and normally was a mixture 3-pyrrolidino methyl) styrene and 4-(pyrrolidino methyl) styrene. The molar ratio of 3-(pyrrolidinomethyl) styrene to 4-(pyrrolidino methyl) styrene was normally closed to 60:40. Also, 0.55 ml of a neat TMEDA and 2.1 ml of 1.6 M n-BuLi were used as the initiator.

The PMS-styrene-butadiene terpolymer produced was determined to have a glass transition temperature (Tg) at -34°C. The Mooney viscosity (ML-4) at 100°C for this polymer was determined to be 37. The GPC data of this polymer was also determined to have a Mn of 147,100 and Mw of 180,600. The polydispersity (Mw/Mn) was 1.23. The polydispersity of this polymer is significantly higher than that of PES-styrene-butadiene terpolymer obtained in Example 1 (1.23 vs. 1.05), indicating side reactions might

occur when PMS was used as a co-monomer.

Example 36

In this experiment, a tin coupled 1/19/80  
5 pyrrolidinoethylstyrene/styrene/1,3-butadiene terpolymer  
was prepared. A total of 2006 grams of a  
silica/alumina/molecular sieve dried premix containing 20.4  
weight percent of pyrrolidinoethyl styrene (PES), styrene  
and 1,3-butadiene in hexane was charged into a one-gallon  
10 (3.8 liters) reactor. The PES to styrene to 1,3-butadiene  
ratio was 1:19:80. Then, 0.52 ml of neat N,N,N',N'-  
tetramethylethylenediamine (TMEDA) and 2.0 ml of 1.6 M n-  
butyl lithium (n-BuLi) in hexane were added to the reactor,  
respectively. The polymerization was carried out at 70°C  
15 for 90 minutes. The GC analysis of the residual monomer  
contained in the polymerization mixture indicated that all  
of the monomer had been consumed by that time. Then, 250  
grams of the polymer cement was removed from the reactor  
and stabilized with 1 phm of antioxidant. Then, 1.30 ml of  
20 a 1 M tin tetrachloride solution in hexane was added to the  
remaining cement in the reactor. The molar ratio of tin  
tetrachloride to n-BuLi was 0.5:1. The coupling reaction  
was conducted at 70°C for 30 minutes. The polymer cement  
was then removed from the reactor and stabilized with 1 phm  
25 of antioxidant. After evaporating the hexane solvent, the  
resulting polymer was dried in a vacuum oven at 50°C.

The PES-styrene-butadiene terpolymer produced was  
determined to have a glass transition temperature (Tg) at  
-35°C. The Mooney viscosity (ML-4) at 100°C for this  
30 polymer was determined to be 81. The Mooney ML-4 viscosity  
of the base polymer was also determined to be 16. The GPC  
data indicated that the coupling efficiency was 75%.



Examples 37-40

In these examples, tin coupled PES-styrene-butadiene terpolymers containing 0.25, 0.5, 2.0 and 5.0% PES were prepared using the procedures described in Example 3 except that the amount of PES was changed from 1.0% to 0.25, 0.5, 2.0 and 5.0%. The molar ratio of tin tetrachloride to n-BuLi was kept the same (0.5:1). The Tg, Mooney viscosity and the percent coupling of these polymers are listed in Table 5.

10

	Example	%PES	Table 5		ML-4 Base Coupled	% Coupling
			Tg (°C)			
15	37	0.25	-36	25	106	80
	38	0.50	-39	19	95	77
	36	1.00	-35	16	81	75
	39	2.00	-35	17	65	-
	40	5.00	-37	16	81	-
20						

Example 41

In this example, a silicone coupled PES-styrene-butadiene terpolymer containing 2.0% PES was prepared using the procedures described in Example 36 except that the amount of PES was changed from 1.0% to 2.0% and silicon tetrachloride was used as the coupling agent. The molar ratio of silicon tetrachloride to n-BuLi was kept the same (0.5:1). The polymer was determined to have a glass transition temperature (Tg) at -36°C. The Mooney viscosity of base and silicon coupled polymers were 17 and 86, respectively.

35

Examples 42-43

In these examples, coupled PES-styrene-butadiene terpolymers containing 1.0% PES were prepared using the

procedures described in Example 36 except that the silicon tetrachloride, and a mixture containing 50% tin tetrachloride and 50% silicon tetrachloride were used as coupling agents. The molar ratio of coupling agent to n-BuLi was kept the same (0.5:1). The glass transition temperature (Tg), Mooney viscosity, and the percent of coupling agent used are listed in Table 6.

Table 6

Example	%PES	Coupling agent	Tg (°C)	ML-4 Base Coupled		% Coupling
42	1.00	SiCl <sub>4</sub>	-32	21	97	81
43	1.00	50/50 SiCl <sub>4</sub> /SnCl <sub>4</sub>	-33	21	89	75

Examples 44-45

In these examples, tin coupled PES-styrene-butadiene terpolymers containing 1.0% PES were prepared using the procedures described in Example 36 except that the molar ratio of tin tetrachloride to n-BuLi was changed from 0.5:1 to 0.25:1 and 0.375:1, respectively. The Tg, Mooney viscosity and the percent coupling of these polymers are listed in Table 7.

Table 7

Example	%PES	SnCl <sub>4</sub> /n-BuLi ratio	Tg (°C)	ML-4 Base Coupled		% Coupling
44	1.00	0.25:1	-36	13	81	81
45	1.00	0.375:1	-37	12	77	77
36	1.00	0.50:1	-35	16	81	75

Comparative Examples 46

In this example, tin coupled PMS-styrene-butadiene terpolymer containing 1.0% PMS was prepared using the

procedures described in Example 36 except that the molar ratio of tin tetrachloride to n-BuLi was changed from 0.5:1 to 0.25:1. The Tg, Mooney viscosity and the percent coupling of this polymer are listed in Table 8. As shown in Table 8, a PES functionalized polymer can be more effectively coupled with tin tetrachloride than the PMS functionalized polymer. Polymers with better tin coupling normally provide better compound properties.

Table 8						
Example	% Functional monomer	SnCl <sub>4</sub> /n-BuLi ratio	Tg (°C)	ML-4 Base Coupled		% Coupling
46	1% PMS	0.25:1	-33	18	65	62
44	1% PES	0.25:1	-36	13	81	81

#### Example 47

In this example, a 1/11/88 PES/styrene/1,3-butadiene terpolymer was prepared using the procedure described in Example 34 except that the ratio of PES to styrene and to 1,3-butadiene was changed to 1:11:80 and the molar ratio of TMEDA to n-BuLi was also changed to 1:1. GC analysis of residual monomer with respect to polymerization time indicated that PES was randomly distributed along the polymer chain. The resulting terpolymer had a Tg at -42°C and was determined to have a ML-4 of 47.

#### Example 48

In this example, a 1/99 PES/isoprene copolymer was prepared using the procedure described in Example 34 except that a mixture of PES and isoprene in hexane was used as the monomer premix and DTP (2,2-di-tetrahydrofuryl propane) was used as the modifier. The molar ratio of DTP to n-BuLi was 2.5:1. GC analysis of residual monomer

indicated that the polymerization was completed in an hour. The resulting copolymer had a Tg at -14°C and was determined to have a ML-4 of 82.

5

Examples 49-65

In this series of experiments tire tread compounds that were loaded with carbon black as a filler were made with styrene-butadiene rubber that had various amounts of a mixture of 3-(2-pyrrolidinomethyl)styrene and 4-(2-pyrrolidinomethyl)styrene (PMS) incorporated therein. The amount of functionalized styrene monomer that was incorporated into the styrene-butadiene rubber is shown in Table 9. These tire tread compositions were made by mixing 55 phr (parts by weight per 100 parts by weight of rubber) of N299 carbon black, 10 phr of processing oil, 3 phr of zinc oxide, 2 phr of stearic acid, 1.5 phr of antioxidant, 1.2 phr of sulfenamide accelerator, and 1.4 phr of sulfur into various styrene-butadiene rubbers having different contents of bound functionalized styrene monomer. The characterization of the tire tread compounds made are shown in Table 9 (G' was measure on uncured compounds and tan delta was measured on cured samples at 60°C).

Table 9

Example	PMS	Macrostructure	ML-4*	G' (kPa)	Tan delta
49	0%	linear	41	500	0.177
50	0%	linear	63	595	0.170
51	0.25%	linear	65	584	0.149
52	0.25%	linear	66	606	0.135
53	0.5%	linear	27	499	0.165
54	0.5%	linear	27	500	0.145
55	0.5%	linear	32	520	0.146
56	0.5%	linear	60	614	0.124
57	0.5%	tin coupled	77	549	0.105
58	1%	linear	47	612	0.116
59	1%	linear	62	645	0.106
60	1%	tin coupled	68	504	0.108
61	2%	linear	25	393	0.160
62	2%	linear	36	466	0.135
63	2%	linear	65	554	0.124
64	5%	linear	46	540	0.115
65	10%	linear	44	581	0.107

\* Mooney ML 1+4 viscosity

5           It is desirable for tan delta to be as low as possible  
at 60°C because the hysteresis of rubber is lower at lower  
tan delta values. Accordingly, tire tread compound that  
have lower tan delta values will have less heat build-up  
and lower rolling resistance. As can be seen from Table 9,  
10 the incorporation of the PMS into the styrene-butadiene  
rubber caused a reduction in tan delta at 60°C. The  
incorporation of 0.25 weight percent of PMS into the  
styrene-butadiene rubber caused a significant reduction in  
tan delta. The incorporation of higher level of bound PMS  
15 into the styrene-butadiene rubber caused greater reduction

in tan delta values.

Examples 66-86

5        In this series of experiments tire tread compounds  
were make with styrene-butadiene rubber that had various  
amounts of a mixture of 3-(2-pyrrolidinoethyl)styrene and  
4-(2-pyrrolidinoethyl)styrene (PES) incorporated therein.  
The amount of functionalized styrene monomer that was  
incorporated into the styrene-butadiene rubber is shown in  
10 Table 10. These tire tread compositions were made as  
described in Examples 49-65. The characterization of the  
tire tread compounds made are shown in Table 10 (G' was  
measure on uncured compounds and tan delta was measured on  
cured samples at 60°C).

Table 10

Example	PES	Macrostructure	ML-4*	G' (kPa)	Tan delta
66	0%	linear	41	500	0.177
67	0%	linear	63	594	0.170
68	0.25%	linear	25	556	0.127
69	0.25%	linear	32	597	0.114
70	0.25%	linear	49	610	0.107
71	0.25%	tin coupled	106	612	0.104
72	0.5%	linear	19	590	0.119
73	0.5%	linear	30	609	0.110
74	0.5%	linear	49	608	0.088
75	0.5%	tin coupled	95	627	0.094
76	1%	linear	16	510	0.122
77	1%	linear	42	620	0.105
78	1%	tin coupled	81	570	0.091
79	2%	linear	17	517	0.110
80	2%	linear	42	619	0.096
81	2%	linear	60	619	0.085
82	2%	tin coupled	65	572	0.091
83	5%	linear	25	605	0.091
84	5%	tin coupled	47	554	0.101
85	5%	linear	48	628	0.084
86	5%	tin coupled	64	672	0.080

\* Mooney ML 1+4 viscosity

5 As has been explained it is desirable for the tan  
delta of tire tread compounds to be as low as possible. As  
can be seen from Table 10, the incorporation of the PES  
into the styrene-butadiene rubber caused a reduction in tan  
delta at 60°C. As can be seen by comparing Table 10 to  
10 Table 9, the incorporation of PES into the styrene-  
butadiene rubber caused a greater reduction in tan delta

than did the incorporation of PMS into the styrene-butadiene rubber.

Examples 87-91

5           In this series of experiments tire tread compounds that were loaded with silica as a filler were made with styrene-butadiene rubber that had various amounts of a mixture of 3-(2-pyrrolidinomethyl)styrene and 4-(2-pyrrolidinomethyl)styrene (PMS) incorporated therein. The  
10 amount of functionalized styrene monomer that was incorporated into the styrene-butadiene rubber is shown in Table 11. These tire tread compositions were made by mixing 55 phr of silica, 10 phr of processing oil, 3 phr of zinc oxide, 2 phr of stearic acid, 1.5 phr of antioxidant,  
15 1.5 phr of sulfenamide accelerator, and 1.4 phr of sulfur into styrene-butadiene rubbers having different contents of bound functionalized styrene monomer. The characterization of the tire tread compounds made are shown in Table 11 (G' was measure on uncured compounds and tan delta was measured  
20 on cured samples at 60°C).

Table 11

Example	PMS	ML-4*	G' (kPa)	Tan delta
87	0%	41	890	0.235
88	1%	47	800	0.157
89	5%	46	596	0.098
90	10%	44	674	0.086
91	20%	47	441	0.088

\* Mooney ML 1+4 viscosity

25           As has been explained it is desirable for the tan delta of tire tread compounds to be as low as possible. As can be seen from Table 11, the incorporation of the PMS



into the styrene-butadiene rubber caused a reduction in tan delta at 60°C. Higher levels of PMS caused greater reductions in tan delta. This series of experiments also that it is possible to eliminate silica coupling agent from  
5 tire tread compounds that are made utilizing styrene-butadiene rubbers that contain a small amount of bound PMS.

#### Examples 92-96

In this series of experiments tire tread compounds  
10 that were loaded with silica as a filler were made with styrene-butadiene rubber that had various amounts of a mixture of 3-(2-pyrrolidinomethyl)styrene and 4-(2-pyrrolidinomethyl)styrene (PMS) incorporated therein. The amount of functionalized styrene monomer that was  
15 incorporated into the styrene-butadiene rubber is shown in Table 11. These tire tread compositions were made by mixing 55 phr of silica, 10 phr of processing oil, 3 phr of zinc oxide, 2 phr of stearic acid, 1.5 phr of antioxidant, 1.5 phr of sulfenamide accelerator, 1.4 phr of sulfur, and  
20 4.4 phr of silica coupling agent into styrene-butadiene rubbers having different contents of bound functionalized styrene monomer. The characterization of the tire tread compounds made are shown in Table 12 (G' was measure on uncured compounds and tan delta was measured on cured  
25 samples at 60°C).

Table 12 (\* Mooney ML 1+4 viscosity)

Example	PMS	ML-4*	G' (kPa)	Tan delta
92	0%	41	754	0.173
93	1%	47	720	0.132
94	5%	46	647	0.098
95	10%	44	617	0.081
96	20%	47	474	0.087

As has been explained it is desirable for the tan delta of tire tread compounds to be as low as possible. As can be seen from Table 12, the incorporation of the PMS  
5 into the styrene-butadiene rubber caused a reduction in tan delta at 60°C. Higher levels of PMS caused greater reductions in tan delta. This series of experiments also that it is possible to reduce the level of silica coupling agent in tire tread compounds that are made utilizing  
10 styrene-butadiene rubbers that contain a small amount of bound PMS and still realize good results.

#### Examples 97-102

In this series of experiments tire tread compounds  
15 that were loaded with silica as a filler were made with styrene-butadiene rubber that had various amounts of a mixture of 3-(2-pyrrolidinoethyl)styrene and 4-(2-pyrrolidinoethyl)styrene (PES) incorporated therein. The amount of functionalized styrene monomer that was  
20 incorporated into the styrene-butadiene rubber is shown in Table 13. These tire tread compositions were made by mixing 78 phr of silica, 28 phr of processing oil, 2.5 phr of zinc oxide, 2 phr of stearic acid, 3 phr of antioxidant, 3 phr of siland coupler, 1.6 phr of sulfenamide  
25 accelerator, 1.9 phr of guanadiene accelerator, and 2.1 phr of sulfur into styrene-butadiene rubbers having different contents of bound functionalized styrene monomer. The characterization of the tire tread compounds made are shown in Table 13 (G' was measure on uncured compounds and tan  
30 delta was measured on cured samples at 60°C).

Table 13

Example	PMS	ML-4*	G' (kPa)	Tan delta
97	0%	41	465	0.145
98	0.25%	49	645	0.151
99	0.5%	49	681	0.141
100	1%	42	657	0.120
101	2%	42	749	0.102
102	5%	48	869	0.073

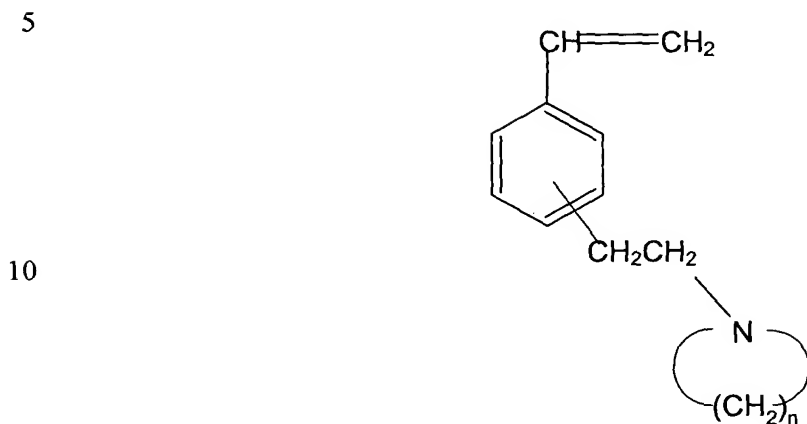
\* Mooney ML 1+4 viscosity

As can be seen from Table 13, the incorporation of the  
5 PES into the styrene-butadiene rubber caused a reduction in  
tan delta at 60°C. Higher levels of PMS caused greater  
reductions in tan delta. This series of experiments also  
that it is possible to reduce the level of silica coupling  
agent in tire tread compounds that are made utilizing  
10 styrene-butadiene rubbers that contain a small amount of  
bound PES and still realize good results.

By utilizing styrene-butadiene rubber that has been  
modified by incorporation a small amount of PES therein  
tire tread compounds can be made that exhibit lower  
15 hysteresis and that can be processed more easily. Silica  
loaded tire tread compounds can also be made with  
significantly lower levels of silica coupling agent. This  
is an extremely important benefit since silica coupling  
agents are expensive relative to most other materials used  
20 in tire tread compounds. The amount of silica coupling  
agent needed in such compounds can typically be reduced to  
a level within the range of 0 phs (parts by weight per 100  
parts by weight of silica) to 5 phs. More typically the  
level of silica coupling agent is reduced to be within the  
25 range of 1 phs to 4 phs. The level of silica coupling  
agent is most typically reduced to a level within the range

of 1 phs to 2 phs.

Functionalized styrene monomers which are of the structural formula:



15 wherein n represents an integer from 4 to about 10 are some of the most beneficial functionalized styrene monomers that can be utilized in the practice of this invention. In such functionalized styrene monomers it is preferred form n to represent 4 or 6. PES (wherein n represents 4) is the most preferred.

20

#### Examples 103-105

##### *Linear Polymerization of 1% PES/19% Styrene/80% Butadiene*

#### 25 Premix Preparation

In the procedure used, 101.4 g of 93% PES in hexane was added to a 20.27% butadiene in hexane premix cylinder via syringe under inert atmosphere to yield a solution with a monomer weight percent ratio of 98.73% 1,3-butadiene and 1.27% PES. The cylinder contained 7,298.6g 1,3-Butadiene, 30 94.3g PES and 28,607.1g hexane. The cylinder contents were mixed using a high shear mixer. Note that the PES can be added to either butadiene or styrene in this manner. A

styrene premix cylinder containing 36,000g of 20.98% styrene in hexane was then prepared.

### Polymerization

5       The desired product was linear  
1PES/19Styrene/80Butadiene SSBR copolymer with a Mooney  
viscosity of 75 and a Tg midpoint of -35°C made  
continuously. Although the desired product specifies 1%  
PES, this copolymer can be synthesized with a range of  
10 0.25%-2% PES. To meet these desired product specifications  
the polymerization was performed under the following  
operating conditions:

- 15       - Monomer weight percent ratio into first reactor of  
1PES/19Styrene/80Butadiene
- 0.6897 mmoles n-butyllithium per 100g monomer  
(Target Mn of 145,000)
- 75 parts 1,2-butadiene per million parts monomer
- 2.0 mmoles TMEDA per mole n-butyllithium
- 20       - Reactor 1 Temp of 194°F
- Reactor 2 Temp of 190°F
- Total retention time of 1 hour

25       The continuous unit contains two one gallon CSTR's in  
series equipped with mechanical agitators under inert  
atmosphere, followed by a five gallon cement holding tank.  
Styrene, 1,3-butadiene and PES, 1,2-butadiene, and TMEDA  
were brought together and then were added to the first  
reactor where they met the n-butyllithium. After achieving  
30 steady state, percent solids were used to monitor total  
monomer conversion, whereas GC analysis provided individual  
monomer consumption. GC results can be seen in Table 14.

The product was collected in a cement tank where it was terminated with 1 mole isopropanol per mole n-BuLi (shortstop) and 1 part per hundred monomer of Paratax (antioxidant). Polymer was air dried in a 130°F oven for three days. Testing of the dry raw polymer includes Mooney Large, DSC, GPC and NMR. Results from these tests can be seen in Tables 15 and 16.

Table 14: Monomer Conversion via Gas Chromatograph

Total % Monomer Conversion			
% Butadiene	%Styrene	%Functional Mon.	%Total Conv.
97.95	96.36	99.88	97.67

10

Table 15: Linear Polymer Characterizations

ML+4	DSC (°C)			GPC Analysis			
	Onset Tg	Inflection Tg	End Tg	Mn	Mw	Mz	Mw/Mn
74	-42.02	-39.32	-36.67	179,500	335,500	640,200	1.87

Table 16: NMR Data for Linear Polymer

					Styrene Sequence			
Trans 1,4-BD	Cis 1,4-BD	1,2-BD	DVCH	Styrene	1S	2-4S	>/=5S	PyrES
24.7	15.6	35.7	5.0	17.8	16.4	1.3	0.1	1.2

15

#### *Coupled Polymerization of 1% PES/19% Styrene/80% Butadiene*

The procedures outlined above were also used for coupled polymerizations with tin tetrachloride, silicon tetrachloride, and a combination of the two. There are only slight variations in the operating conditions. The coupling agent was added in a ratio of 0.25 moles coupling agent per mole n-butyllithium.

25

The 1% PES/19% styrene/80% 1,3-butadiene SSBR copolymer having a base Mooney viscosity of 35 was coupled continuously with a linear base to attain a coupled Mooney viscosity of 90 and a midpoint glass transition temperature

(T<sub>g</sub>) of -35°C. To meet these specifications the polymerization was performed under the following operating conditions:

- 5           - Monomer weight percent ratio into first reactor of 1PES/19Styrene/80Butadiene
- 0.8091 mmoles n-butyllithium per 100g monomer (Target Mn of 120,000)
- 75 parts 1,2-butadiene per million parts monomer
- 10          - 2.0 mmoles TMEDA per mole n-butyllithium
- 0.25 moles 2% coupling agent (both SnCl<sub>4</sub> and SiCl<sub>4</sub>) in hexane per mole n-butyllithium
- Reactor 1 Temp of 194°F
- Reactor 2 Temp of 190°F
- 15          - Total retention time of 1 hour

The coupling agent is introduced to the polymerization in a high shear cement mixer located after the second reactor and before the cement holding tank. The hold time in the cement mixer is approximately four minutes. Tables 17-19 include characterization data for these copolymers.

Table 17: Monomer Conversion via Gas Chromatograph

Total % Monomer Conversion			
% Butadiene	%Styrene	%Functional Mon.	%Total Conv.
99.03	98.65	99.88	98.97

5 Table 18: Linear Polymer Characterizations

ML+4 Base SnCl <sub>4</sub> SiCl <sub>4</sub>	DSC (°C)			GPC Analysis			
	Onset Tg	Inflection Tg	End Tg	Mn	Mw	Mz	Mw/Mn
42	-38.5	-35.8	-33.0	127,000	274,800	647,800	2.16
88	-40.1	-36.7	-33.3	147,900	424,100	1,471,000	2.87
74	-39.0	-36.2	-33.4	148,500	392,900	1,158,000	2.65

Table 19: NMR Data for Linear Polymer

					Styrene Sequence			
Trans 1,4- BD	Cis 1,4 - BD	1,2- BD	DVCH	Styre ne	1S	2-4S	>/=5S	PyrES
21.3	15.3	37.4	5.0	20.1	18.3	1.4	0.5	0.9

10 *Coupled Polymerization of 0.5% PES/19.5% Styrene/80%  
Butadiene*

Once again, the procedures outlined above were used for coupled polymerizations with tin tetrachloride, silicon tetrachloride. There are only slight variations in the operating conditions. The coupling agent was added in a ratio of 0.25 moles coupling agent per mole n-butyllithium.

The 1% PES/19% styrene/80% 1,3-butadiene SSBR copolymer having a base Mooney viscosity of 35 was coupled continuously with a linear base to attain a coupled Mooney viscosity of 90 and a midpoint glass transition temperature (Tg) of -35°C. To meet these specifications the polymerization was performed under the following operating conditions:

25

- Monomer weight percent ratio into first reactor of



1PES/19Styrene/80Butadiene

- 0.8091 mmoles n-butyllithium per 100g monomer  
(Target Mn of 120,000)
- 75 parts 1,2-butadiene per million parts monomer
- 5 - 2.0 mmoles TMEDA per mole n-butyllithium
- 0.25 moles 2% coupling agent (both SnCl<sub>4</sub> and SiCl<sub>4</sub>)  
in hexane per mole n-butyllithium
- Reactor 1 Temp of 194°F
- Reactor 2 Temp of 190°F
- 10 - Total retention time of 0.5 hours

The coupling agent is introduced to the polymerization in a high shear cement mixer located after the second reactor and before the cement holding tank. The hold time in the cement mixer is approximately four minutes. Tables 20-22 include characterization data for these copolymers.

Table 20: Monomer Conversion via Gas Chromatograph

Total % Monomer Conversion			
% Butadiene	%Styrene	%Functional Mon.	%Total Conv.
98.55	96.69	99.55	98.14

20

Table 21: Linear Polymer Characterizations

ML+4	DSC (°C)			GPC Analysis			
Base SnCl <sub>4</sub> SiCl <sub>4</sub>	Onset Tg	Inflection Tg	End Tg	Mn	Mw	Mz	Mw/Mn
32	-37.7	-35.1	-32.4	120,100	189,400	276,200	1.58
73	-38.1	-34.8	-31.5	190,100	468,500	960,800	2.46
86	-38.8	-35.6	-32.7	192,000	430,100	704,500	2.24

Table 22: NMR Data for Linear Polymer

					Styrene Sequence			
Trans 1,4- BD	Cis 1,4 - BD	1,2- BD	DVCH	Styre ne	1S	2-4S	>/=5S	PyrES
22.1	15.5	37.5	4.9	19.6	17.5	1.9	0.2	0.4

Examples 106-108

High Trans SBR

Polymerization of styrene, 1-pyrrolidino-ethyl styrene  
5 (PES) and butadiene was carried out in a one-gallon glass  
bowl batch reactor, under a blanket of nitrogen, equipped  
with a mechanical stirrer and temperature control via  
cooling water and low pressure steam. Both butadiene and  
styrene premixes contained approximately 20% monomer  
10 dissolved in hexane. The reactor was charged with 1% PES,  
9% styrene in hexane and 90% butadiene in hexane to  
synthesize the appropriate polymer. The catalyst was added  
at room temperature, and within minutes of addition, the  
reactor temperature was 90°C. The catalyst system for this  
15 polymer consisted of an alkylated Barium diethyleneglycol  
ethylether (BaDEGEE) and Trioctyl aluminum (TOA) in a 1  
(BaDEGEE) to 4 (TOA) ratio and n-butyllithium. The addition  
of this catalyst is critical for a successful  
polymerization. The alkylated BaDEGEE and TOA solution was  
20 prepared by adding the appropriate amount of TOA to BaDEGEE  
and heated for 30 minutes at 70°C. Pyrrolidine and TMEDA  
can also be used as a modifier in this catalyst in a ratio  
of 1/1 amine/BaDEGEE, and they are typically added in this  
alkylation step. Here, 0.80 mmol of BaDEGEE per 100 grams  
25 of polymer was used to initiate polymerization. The  
alkylated BaDEGEE/TOA solution (with or without amine  
present) was added to a clean bottle and the correct amount  
of n-BuLi (in a ratio of 3 n-BuLi to 1 BaDEGEE) was added.  
The final solution had a ratio of 1/4/3/1 BaDEGEE/TOA/n-  
30 BuLi/amine (if used). This solution was shaken for several  
minutes at room temperature, and then it was injected as  
the initiator. Samples were taken over the course of the  
reaction to determine monomer conversion. According to gas

chromatography, the PES monomer appeared to react much faster than the butadiene or styrene, see Figure 1. All reactions were short-stopped with denatured ethanol, and 2,6 - ditertbutylphenol was added to the polymer cement.

5 The polymer was then dried for several days in a hot oven to make sure all solvent had evaporated. Table 1 summarizes the data for this system:

High Trans IBR

10 Using the same procedure and catalyst system as above, polymerization of PES, isoprene and butadiene was carried out. The only difference was that the reactor was charged with 1% PES, 9% isoprene and 90% butadiene. All other conditions were identical. Figure 2 illustrates monomer  
15 conversion versus time. Polymer characteristics are shown in Table 1.

High Trans SIBR

20 Using the same procedure and catalyst system outlined above, polymerization of PES, styrene, isoprene and butadiene was carried out. The only difference was that the reactor was charged with 1% PES, 9% isoprene + styrene (2.5, 4.5 and 7.5% isoprene) and 90% butadiene. All other conditions were identical.

25 Table 23: Polymer characteristics for PES containing high trans polymers

Sample	Tg (onset)	Tg (midpt.)	Tm	Mn	Mw	PDI	ML+4
1/9/90 HTPESSBR	-83.4°C	-76.0°C	24.2°C	135K	191K	1.42	57
10/90 HTSBR	-86.0°C	-79.7°C	17.6°C	102K	164K	1.61	66

Table 24: NMR Results for PyrES High Trans polymers

Sample	Trans 1,4-BD	Cis 1,4- BD	1,2-BD	Styrene	PyrES
1/9/90 HTPESSBR	76.0	13.2	3.4	6.5	0.9
10/90 HTSBR	75.2	13.8	3.5	7.5	—

5

Example 109

In this experiment, a low vinyl polybutadiene containing 5% pyrrolidinoethylstyrene (PES) was prepared. In the procedure, 1000 grams of a silica/alumina/molecular sieve dried premix containing 19 weight percent of 1,3-butadiene in hexanes was charged into a one-gallon (3.8 liter) reactor. Then, 10.2 grams of a 93% PES was added to the reactor. The PES used consisted of a 93% mixture of 3-(2-pyrrolidinoethyl) styrene and 4-(2-pyrrolidinoethyl) styrene and a 7% mixture of 3-(2-pyrrolidinoethyl)-1-ethylbenzene and 4-(2-pyrrolidinoethyl)-1-ethylbenzene. The polymerization was initiated with 1.9 ml. of 1 M n-butyllithium (in hexane). The polymerization was carried out at 90°C for 90 minutes. The progress of the polymerization was monitored by analyzing the residual monomer contained in the polymerization mixture using a GC. The GC analyses indicated that the PES co-polymerized randomly with 1,3-butadiene and all monomers were consumed after 60 minutes. The polymer cement was then shortstopped with ethanol and was subsequently removed from the reactor and stabilized with 1 phm of antioxidant. After evaporating the hexane solvent, the resulting polymer was dried in a vacuum oven at 50°C.

The PES-butadiene copolymer produced was determined to

have a glass transition temperature (T<sub>g</sub>) at - 83°C. The Mooney viscosity (ML-4) at 100°C for this polymer was determined to be 60.

5

Examples 110-112

In these experiments, low vinyl polybutadienes contained 2% and 1% PES were prepared using a procedure similar to the procedures described in Example 109 except that the amount of PES utilized was 1% or 2% rather than 10 5%. The glass transition temperature (T<sub>g</sub>) and vinyl content of the resulting rubbery polymers are listed in Table 1.

Table 25

Example	PES	T <sub>g</sub>	Vinyl Content
110	5%	-83°C	18%
111	2%	-92°C	11%
112	1%	-94°C	9%

15

Comparative Example 113

In this experiment, a low vinyl polybutadiene rubber was prepared using the procedure as described in Example 109 except that no PES was copolymerized into the polymer. 20 The glass transition temperature (T<sub>g</sub>) of the resulting polybutadiene rubber was -98°C and its vinyl content was 8%.

Example 114

25

In this experiment, a low vinyl polyisoprene containing 5% PES was prepared. The procedure described in Example 109 was used except that isoprene was used as the main monomer and the polymerization was conducted at a temperature of 65°C. The GC analyses of the residual 30 monomers indicated that the PES monomer randomly

copolymerized with the isoprene throughout the polymerization and that all monomers were consumed after 100 minutes of polymerization time. The glass transition temperature (T<sub>g</sub>) of the polyisoprene rubber was -56 and it  
5 had a Mooney ML-4 viscosity of 82.

#### Example 115

In this experiment, a low vinyl polyisoprene rubber containing 1% bound PES was prepared. The procedure  
10 described in Example 114 was used except in this experiment 1% of the PES monomer was copolymerized into the polymer. Again, GC analyses of the residual monomers showed that PES was randomly distributed along the polymer chains. The glass transition temperature and Mooney ML-4 viscosity of  
15 the resulting polyisoprene rubber were -63.4°C and 70, respectively.

#### Comparative Example 116

In this experiment, a low vinyl polyisoprene rubber was  
20 prepared utilizing a procedure that is similar to the one described in Example 114 except that no PES was was copolymerized into the polymer. The glass transition temperature and vinyl content of the resulting polyisoprene rubber were -65°C and 8%, respectively.

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#### Example 117

Vinylbenzylic anion is generated from vinyltoluene with metal salts of amines, such as lithium  
diisopropylamine (LDA), sodium diisopropylamine, lithium  
30 diethylamine, lithium methylamine, in the presence of free primary and secondary amines, which can be the same or different from the metal amide. Accordingly, 2.02 grams of diisopropylamine (20 mmol) was dissolved in 20 ml of dried

tetrahydrofuran (THF) under a nitrogen atmosphere with 6.5 ml of 1.6 M BuLi (10 mmol) solution in hexane being added to generate the lithium amide in situ. Then 1.2 grams of vinyltoluene (10 mmol) was added in one portion. The presence of the free amine prevented polymerization and made the metal amide a stronger agent for metallation. The desired vinylbenzylic anion was generated in an equilibrium with the amide.

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#### Example 118

Reaction of the vinylbenzylic anion synthesized in Example 117 with a halogenated reagent, such as trimethylchlorosilane, produces functionalized styrene monomer. Accordingly, a solution containing 1.2 grams of trimethylchlorosilane (11 mmol) in 5 ml THF was slowly added over a period of 3 hours at 20°C to the vinylbenzylic anion solution made in Example 117. Analysis by gas chromatography showed a 50% yield with peaks identified as regents and both mono and bis-adducts. After washing with dilute a dilute hydrochloric acid (HCl) solution 3 times, the solvent was evaporated and the producted was distilled under vacuum. NMR confirmed that the fraction collected at 100-120°C and 0.5 mmHg of vacuum contained trimethylsilylmethylstyrene as a major product.

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#### Example 119

In this experiment the synthesis of trimethylsilylmethylstyrene was scaled-up to a 2-liter flask. After purging the flask with nitrogen gas for one hour, 500 ml dried THF was added and purged with nitrogen for half an hour. Then, 630 ml of 1.6 M BuLi solution in hexane (1.0 mol) was added and the flasked was cooled to 0°C and then 280 ml of dried diisopropylamine (2.0 mol) was

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added dropwisely to the flask, followed by addition of 132 ml of *p*-methyl-styrene (1.0 mol). The temperature was maintained at about 20°C and 120 grams of trimethylchlorosilane (1.1 mol) in 100 ml THF was slowly added over a period of 4 hours. After washing three times with a dilute aqueous HCl solution, the organic phase was dried and concentrated. Distillation under vacuum gave the desired trimethylsilylmethylstyrene compound. Both GC and NMR confirmed the existence of the functional groups.

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#### Example 120

The general procedure described in Example 119 can be used to prepare other functionalized styrene monomers with other halogenated reagents. Thus, in the procedure described in Example 119, by substituting 1.1 mole of chlorodiphenylphosphine (243 g) for the 1.1 mole of trimethylchlorosilane (120 g), a new functional styrene (diphenyl-vinylbenzyl-phosphine) can be synthesized. The method provides a general monomer synthesis methodology to generate an vinylbenzyl anions using vinyltoluene and various electrophile agents selected from Cl-Si-(CH<sub>3</sub>)<sub>3</sub>, Cl-(CH<sub>2</sub>)<sub>3</sub>-Si-(OCH<sub>3</sub>)<sub>3</sub>, Cl-(CH<sub>2</sub>)<sub>3</sub>-Si-(CH<sub>3</sub>)-(OCH<sub>3</sub>)<sub>2</sub>, Cl-P-Ph<sub>2</sub>, Cl-P-Et<sub>2</sub>, Cl-P-Cyclohexyl<sub>2</sub>, Cl-(CH<sub>2</sub>)<sub>2</sub>-N-(C<sub>4</sub>H<sub>9</sub>), Cl-(CH<sub>2</sub>)<sub>2</sub>-N-(CH<sub>3</sub>)<sub>2</sub>, Cl-(CH<sub>2</sub>)<sub>2</sub>-O-CH<sub>3</sub>, Cl-(CH<sub>2</sub>)<sub>2</sub>-O-(CH<sub>2</sub>CH<sub>3</sub>)<sub>2</sub>, Cl-Sn-(C<sub>4</sub>H<sub>9</sub>)<sub>3</sub>, Cl-Sn-(CH<sub>3</sub>)<sub>3</sub>, and Br-Sn-(C<sub>4</sub>H<sub>9</sub>)<sub>3</sub>.

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#### Example 121

In this experiment, a trimethylsilylmethyl styrene/styrene/1,3-butadiene terpolymer was prepared. In the procedure utilized, 1930 grams of a silica/alumina/molecular sieve dried premix containing 21.31 weight percent trimethylsilylmethyl styrene (TMSMS), styrene and 1,3-butadiene in hexanes was charged into a

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one-gallon (3.8 liters) reactor. The TMSMS to styrene to 1,3-butadiene ratio was 1:16:83. In the procedure used, 0.49 ml of neat N, N, N', N'-tetramethylethylenediamine (TMEDA) and 2.3 ml of 0.97 M n-butyl lithium (n-BuLi) in  
5 hexane were added to the reactor, respectively. The molar ratio of TMEDA to n-BuLi was 1.5:1. The polymerization was carried out at 70°C for 150 minutes. The GC analysis of the residual monomer contained in the polymerization  
10 mixture indicated that the all monomers were consumed at that time, and the polymer cement was then shortstopped with ethanol and subsequently removed from the reactor and stabilized with 1 phm of antioxidant. After evaporating hexane, the resulting polymer was dried in a vacuum oven at 50°C. The GC analysis of the residual monomer with respect  
15 to the polymerization time also indicated that even thorough TMSMS polymerized much slower than the 1,3-butadiene and styrene, most of TMSMS was randomly distributed along the polymer chain.

The TMSMS-styrene-butadiene terpolymer produced was  
20 determined to have a glass transition temperature (Tg) at -32°C. It was also determined to have a microstructure which contained 49.7 percent 1,2-polybutadiene units, 31.2 percent 1,4-polybutadiene units, 16.3 percent random polystyrene units and 0.7 percent of TMSMS units. The  
25 Mooney viscosity (ML-4) at 100°C of the polymer was determined to be 62.

#### Example 122

In this experiment, an emulsion a  
30 styrene/butadiene/pyrrolidinoethyl styrene (PES) terpolymer was prepared. In the procedure used, 7.29 lbs. of soft water, 4.76 grams of sodium naphthalenesulfonate-formaldehyde dispersant (Daxad 14B from Hampshire Chemical

Co., 47.5% active), 7.2 gms. of tripotassium phosphate, 140 grams of disproportionated rosin acid (potassium salt, 20% solution in water at pH 9.5), and 532 grams of C14-18 and C16-18 unsaturated fatty acids (potassium salt, 10% solution in water at pH 9.5) were charged into a 2-gallon stainless steel reactor. Prior to charging to the reactor, the pH of the solution was adjusted to 10.2-10.8 by the addition of a 10% aqueous potassium hydroxide solution. Then, 100 grams of soft water, 0.32 grams of ethylenediaminetetraacetic acid/ferric sodium complex (Akzo Nobel Chemicals Co.) and 1.08 grams of sodium formaldehyde sulfoxylate were added. Then, 580 grams of styrene, 22.5 grams of PES (92% purity), and 4.5 grams of tert-dodecylmercaptan were added.

The reactor was evacuated for about 30 minutes and 1400 grams of 1,3-butadiene was added. At a temperature of 10°C, 1.82 grams of pinane hydroperoxide (44% active) was added. The emulsion polymerization was initiated at a temperature of 10°C with the reactor being agitation at 300 rpm. After 7 hours at a conversion of about 65% the polymerization was shortstopped by the addition of a solution of 160 grams of water, 0.64 grams of potassium hydroxide, 1.5 grams of the sodium salt of N,N-diethyldithiocarbamate(40% active), and 0.71 grams of N,N-diethylhydroxylamine (85% active).

After stripping off the unreacted monomers under vacuum using a rotary evaporator, a sample of the latex (about 24.7% solids) with 1 part added of Polystay® C antioxidant per 100 parts dry rubber and 1 part added of Polygard antioxidant (Uniroyal Chemical Co.) per 100 parts dry rubber was coagulated and the rubber crumb dried. The coagulation was carried out using 3000 grams of water, 30 grams of sodium chloride, and 1 gram of an ethylene amine

mixture with vigorous agitation at 160-180°F. A 10 weight percent aqueous sulfuric acid solution was slowly added to the coagulation solution to maintain the pH within the range of 3 to 4. The resulting rubber crumb was washed  
5 with water and dried at 150°F in a forced air oven.

The Mooney viscosity at 100°C of the rubber was 44. The bound styrene content and PES content of the polymer were determined by NMR to be 24.0% and 0.9% respectively. The midpoint glass transition temperature of the rubber was  
10 determined by DSC (Differential Scanning Calorimetry) to be -52°C and the onset glass transition temperature was determined to be -56°C.

#### Comparative Example 123

15 In this experiment, a control emulsion styrene/butadiene copolymer was made in a 2-gallon stainless steel reactor using the procedure described in Example 122 except that no PES was used and 600 grams of styrene and 5.1 grams of tert-dodecylmercaptan were used.  
20 After 6.25 hours of polymerization time and approximately 65% conversion, the emulsion polymerization was shortstopped. After coagulation and drying the rubber crumb of the emulsion styrene/butadiene copolymer exhibited a Mooney viscosity (100°C) of 45, a midpoint glass  
25 transition temperature of -53.6°C and an onset glass transition temperature of -56°C. NMR showed a bound styrene level of 23.2%.

#### Example 124

30 In this experiment, an emulsion styrene/butadiene/pyrrolidinoethyl styrene (PES) terpolymer was prepared in a larger reactor. In the procedure utilized, 40.1 lbs. of soft water, 33 grams of sodium

naphthalenesulfonate-formaldehyde dispersant (Daxad 14B from Hampshire Chemical Co., 47.5% active), 25.5 grams of potassium chloride, 767 grams of disproportionated rosin acid (potassium salt, 20% solution in water at pH 9.5),  
5 2927 grams of C14-18 and C16-18 unsaturated mixed fatty acids (potassium salt, 10% solution in water at pH 9.5), and 5.82 grams of tripotassium phosphate were charged into a 10-gallon stainless steel reactor. Prior to charging to the reactor, the pH of the solution was adjusted to 10.2-  
10 10.8 with 20% potassium hydroxide. Next, 440 grams of soft water, 1.26 grams of ethylenediaminetetraacetic acid, ferric sodium complex (Akzo Nobel Chemicals Co.), and 7.75 grams of sodium formaldehyde sulfoxylate were added. Then, 3245 grams of styrene, 59.8 grams of PES (92% purity by  
15 GC), and 16.0 grams of tertiary dodecylmercaptan were added. The reactor was evacuated for 15 minutes, and 7700 grams of 1,3-butadiene was added. At 10°C, 10 grams of pinane hydroperoxide (55% active) was added. The emulsion polymerization was initiated at a temperature of 10°C with  
20 the reactor being agitated at a speed of 250 rpm with two AFT blades. After 6.25 hours and about 65% conversion, the polymerization was shortstopped with a solution of 880 grams of soft water and 44 grams of isopropylhydroxylamine (15% active).

25 After stripping off the unreacted monomers under vacuum, 1 part of Polystay® C antioxidant per 100 parts of dry rubber and 1 part of Polygard (Uniroyal Chemical Co.) per 100 parts dry rubber were added to the sample of the latex and it was coagulated. The rubber crumb was washed  
30 with water and dried at 150°F in a forced air oven. The coagulation was carried out using a mixture containing 3000 grams soft water, 30 grams of sodium chloride and 1 gram of ethylene amine with vigorous agitation at 160-180°F.

Sulfuric acid (10% wt.) was added to the coagulation solution to maintain the pH at 3-4 as the latex was sloely added. The Mooney viscosity (100°C) of the rubber was 107. The bound styrene content (by NMR) was 23.8% and the PES  
5 was 0.4% (by NMR). A colorimetric analysis method showed PES content of 0.47 weight percent.

#### Example 125

In this experiment, an emulsion styrene/butadiene/ 3-  
10 (2-pyrrolidino-1-methyl ethyl)-1-alpha-methyl styrene (PAMS) terpolymer was prepared. To a 2-gallon stainless steel reactor, 7.29 lbs. of soft water, 4.76 grams of sodium naphthalenesulfonate-formaldehyde dispersant (Daxad 14B from Hampshire Chemical Co., 47.5% active), 7.2 grams  
15 of tripotassium phosphate, 140 grams of disproportionated rosin acid (potassium salt, 20% solution in water at pH 9.5), and 532 grams of C14-18 and C16-18 unsaturated fatty acids (potassium salt, 10% solution in water at pH 9.5) were charged. Prior to charging to the reactor, the pH of  
20 the solution was adjusted to 10.2-10.8 with 10% potassium hydroxide. Next, 100 grams of soft water, 0.32 gram of ethylenedidaminetetraacetic acid/ferric sodium complex (Akzo Nobel Chemicals Co.), and 1.08 grams of sodium formaldehyde sulfoxylate were added. Then, 580 grams of  
25 styrene, 20 grams of 3-(2-pyrrolidino-1- methyl ethyl)-1-alpha-methyl styrene (PAMS, 100% purity), and 4.4 grams of tert-dodecylmercaptan were added. The reactor was evacuated for about 30 minutes, and 1400 grams of 1,3-butadiene was added. At 10°C, 1.82 grams of pinane  
30 hydroperoxide (44% active) was added. The emulsion polymerization was initiated at 10°C with reactor agitation using two AFT blades at 300 rpm. After 5 hours and about 65% conversion, the polymerization was shortstopped with a

solution of 8 grams isopropylhydroxylamine (15% active) and 180 grams of soft water. After stripping off the unreacted monomers under vacuum using a rotary evaporator, a sample of the latex with 1 part added Polystay® C antioxidant per 100 parts dry rubber and 1 part added of Polygard (Uniroyal Chemical Co.) per 100 parts dry rubber was coagulated and the rubber crumb dried. The coagulation was carried out using 3000 grams of water, 30 grams of sodium chloride, and 1 gram of ethylene amine mixture with vigorous agitation at a temperature of 160-180°F. A 10 weight percent aqueous sulfuric acid solution was added to the coagulation solution to maintain the pH at 3-4 as the latex was added slowly. The resulting rubber crumb was washed with water and dried at 150°F in a forced air oven. The Mooney viscosity (100°C) of the rubber was 43.5. The bound styrene content (by NMR) was 22.9% and the PAMS was 0.4% (nmr). The midpoint glass transition temperature was -55°C by DSC (Differential Scanning Calorimetry) and the onset glass transition temperature was -58°C.

Variations in the present invention are possible in light of the description of it provided herein. While certain representative embodiments and details have been shown for the purpose of illustrating the subject invention, it will be apparent to those skilled in this art that various changes and modifications can be made therein without departing from the scope of the subject invention. It is, therefore, to be understood that changes can be made in the particular embodiments described which will be within the full intended scope of the invention as defined by the following appended claims.